The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY
WILLIAM H. EMMONS, DIRECTOR

IN CO-OPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 11

PRELIMINARY REPORT ON THE CLAYS AND SHALES OF MINNESOTA

BY

FRANK F. GROUT

AND

E. K. SOPER

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THE CLAYS AND SHALES OF MINNESOTA

OUTLINE OF PAPER

This paper discusses briefly the distribution, origin, properties, classification, and adaptability of the clays and shales of Minnesota. An attempt has been made to test all the more important deposits with sufficient care and exactness to determine the purposes for which they may be used. To render the data more readily accessible the following outline is given.

Detailed results of tests are stated in Chapter VII. The technical terms used in the discussion are briefly explained in the sections on Technology and Physical Properties, Chapters II and IV.

In Chapter VI certain areas are recommended for prospecting and development. Fire clays are to be found in the central to southwestern parts of the State, and semi-refractory clays are somewhat more widely distributed. These should be sought by drilling.

The general character of each geologic formation and the character of the clay products made from them by various methods of manufacture are given in the latter part of Chapter V. The map, Plate I, shows the main features of the distribution of clays.

As stated in Chapter V, the gray drift is widely distributed and is one of the most important sources of clay in the State. After the limestone pebbles have been removed, it can be made into excellent drain tile, for which there will be an increasing market as the swamp lands of the State are drained. The expense of the process of removing the limestone is not so great as to be prohibitive. Some details of the process are given in Chapter IV.

It is believed that an excellent fancy brick may be made from the upper Huronian slates at Carlton and vicinity (page 79) if a small percentage of red drift is added.

Deposits suitable for common brick are abundant and widely distributed. The red drift, capable of making vitrified brick, is distributed in many accessible localities in the eastern part of the State. The red laminated clays of the eastern counties make good red brick and may be used as a slip glaze for semi-refractory ware.

CHAPTER I

INTRODUCTION

OBJECTS AND SCOPE OF PAPER

This bulletin is a preliminary paper outlining the principal results of an investigation of the clay resources of Minnesota, which was carried on during the summer of 1912. A more comprehensive report is now in progress and will be issued later. In general, the object of the work has been to assist in the development of the clay resources of Minnesota. The broader problems of ceramics are treated only incidentally. Some of the important scientific conclusions of the American Ceramic Society, of the Bureau of Standards, and of surveys of other states are briefly reviewed here in order that they may be more readily available to those whose chief interests are technical and commercial. A more extended treatment of the scientific results of the investigation will appear later.

Specifically, the object has been (1) to investigate the sources of clay for every town of 1,000 or more inhabitants, and for each county of the State; (2) to ascertain the extent of several deposits now developed at only a few points; (3) to find new deposits; and (4) to determine the qualities of these deposits and of certain mixtures, to ascertain whether it is possible to produce some refractory wares, pottery, paving brick, and certain other high-grade products that are now carried considerable distances to the Minnesota markets.

ACKNOWLEDGMENTS

The work has been done in coöperation with the United States Geological Survey, and it is planned to issue the final bulletin on the coöperative basis. Acknowledgments are given to Messrs. Oliver Bowles, George L. Harrington, and F. M. Handy, who assisted in the work, and to Messrs. Frank Leverett, F. W. Sardeson, and A. W. Johnston for contributions of certain geological data; to Mr. Jefferson Middleton, of the United States Geological Survey, for lists of producers; to the United States Bureau of Standards for tests; to the Minnesota School of Mines Experiment Station for firing tests; to the Experimental Engineering Department of the University for tests of the products; to J. G. Houghton, Minneapolis Inspector of Buildings, for tests of brick and tile; and to Dr. C. P. Berkey for unpublished data collected in 1902. The work in the field has been greatly facilitated by the friendly coöperation of Commercial Clubs and other organizations of similar purpose, and by many indi-

viduals. Sincere thanks are due Mr. M. C. Madsen, of Hutchinson, Messrs. E. S. Hoyt and J. H. Rich, of Red Wing, Dr. O. C. Strickler, of New Ulm, and many others.

DEFINITIONS

Clay is defined in two ways: (1) an earthy aggregate consisting essentially of the mineral kaolinite, or some nearly related hydrous aluminum silicate; (2) any earthy mass which becomes plastic when wet. The mineral kaolinite has the composition $H_4Al_2Si_2O_9$; its specific gravity is 2.6; it is monoclinic in crystal form; it is white, unless impure. Halloysite, pyrophyllite, cimolite, bauxite, and opal are species frequently associated with kaolinite. Shale is a term frequently employed in the same sense as clay, but as a rule it is applied to hard, laminated clays, generally of marine origin.

ORIGIN OF CLAY

All, or nearly all, of the clay minerals are secondary in origin, and are derived by the hydrous alteration of other silicate minerals, components of the so-called crystalline rocks. The following list shows approximately the chemical composition of the most common rock-making silicates.

Orthoclase = potassium aluminum silicate
Albite = sodium aluminum silicate
Anorthite = calcium aluminum silicate
Muscovite = hydrous potassium aluminum silicate
Biotite = iron magnesian aluminum silicate
Hornblende = a complex silicate containing as a rule iron, magnesium, calcium, and aluminum
Augite = ditto.

By various natural reactions some or all of these minerals are commonly altered to kaolinite or the related clay materials. The particular circumstances under which natural reactions produce kaolinite from other minerals have been the subject of considerable discussion, especially as regards those reactions which have produced large bodies of relatively pure kaolinite. It has been stated that the action of hydrofluoric acid may form kaolinite from orthoclase at great depths in the earth, but it seems probable that only a very small portion of the kaolinite known has been so formed. The slower, but more general, process of weathering at the surface is of much greater importance. Weathering is usually, but not invariably, accompanied by processes of erosion and sedimentation.

ROCK WEATHERING

Weathering includes both chemical effects, known as decomposition, and mechanical effects known as disintegration, which are usually

simultaneous and closely related. Many rock minerals are partially soluble in circulating water, and, as a part of the mineral is removed, water may combine with the residue, producing hydrous minerals. (See Fig. 1.) These are usually softer and more loosely bound together than the original minerals, and hence are more easily affected by mechanical processes. The mechanical processes are erosion by streams carrying sediments, erosion by wind-blown sand, by ice, by the pounding of waves, by the unequal expansion resulting from alternation of heat and cold, etc. All the mechanical processes result in breaking up rocks into finer particles than the original, so that circulating water has easier access to bring about decomposition.

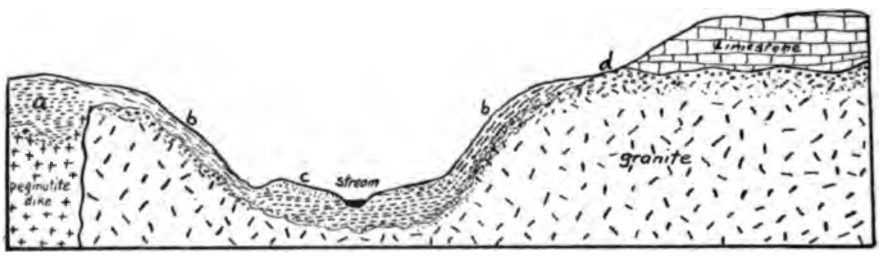

FIGURE I. ILLUSTRATING THE ORIGIN OF CLAYS.
a. RESIDUAL CLAY, KAOLIN. *b.* COLLUVIAL CLAY.
c. ALLUVIAL CLAY. *d.* DECOMPOSED GRANITE, PARTIALLY ALTERED TO CLAY.

The solvent action of circulating water on minerals is greatly increased by the presence of dissolved gases and salts. Carbonic acid and oxygen are especially effective, and the organic products of bacteria and animal and vegetable life in general are noteworthy.

The result of weathering on rocks depends largely upon the relative amounts of decomposition and disintegration. A powder formed chiefly by the grinding up of crystalline rocks must naturally have properties radically different from one formed by the chemical solution of part of the rock. One is spoken of as "rock flour," and the other as "rock rot." Glacial erosion, for example, is mostly mechanical and yields rock flour. The finest particles which result from weathering in either case usually constitute a clay, and, by the nature of the process of formation, such clay is likely to be mixed with numerous remnants of the original minerals from which it was formed. An elaborate discussion of weathering, with a bibliography, is to be found in Vol. XIII of the Transactions of the American Ceramic Society.

EROSION AND SEDIMENTATION

Most important are the processes of erosion and sedimentation. Clay particles formed by weathering are finer grained than particles of the sand and gravel, and, when washed by water, a separation is often accomplished. The carrying power of running water varies greatly with its velocity. Thus a stream which under normal conditions would gather up and carry particles of clay, might not flow fast enough to carry grains of sand except at times of great floods. This separation is of great importance in the accumulation of large bodies of clay free from sand. Some streams flow fast enough at all seasons to carry both the sand and clay, yet a later sorting process may occur and yield beds of clay free from sand, for, where such streams reach a lake or the ocean, the currents are checked only partially at first, and the coarser sand is deposited near shore, while the clay accumulates farther out. Similarly, shore currents and waves may separate sand from clay and the latter may be deposited farther from the shore.

ALTERATION

After the formation of a clay, geologic processes may modify it in many ways. Circulating waters may leach from it certain soluble elements (see Fig. 2) or, on the other hand, may deposit mineral matter as cement or as concretionary masses. An increase of temperature may dehydrate it and destroy the minerals present. By these and similar processes a clay deposit may be changed.

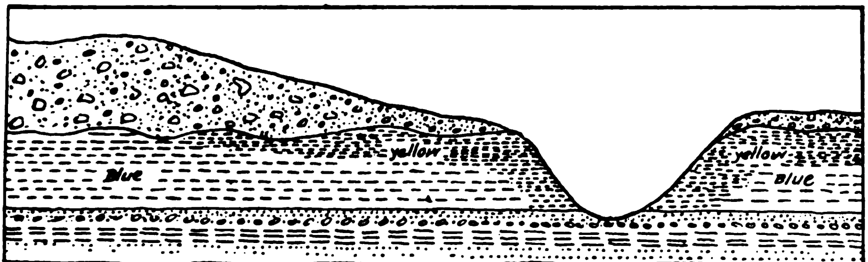

Fig. 2
Sketch showing influence of thickness of drift on depth of weathering of clay

GEOLOGIC TYPES OF DEPOSITS

1. RESIDUAL DEPOSITS

The weathering and superficial decay of granitic igneous rocks sometimes produces a sheetlike mantle of clay of great lateral extent and as much as 100 feet in thickness. As a rule such deposits follow the irregularities of the original rock surface, their base depending more or less

closely upon the water level and the topography at the time they were formed. Another less common form of residual clay results from the alteration of igneous dikes. The impurities depend largely upon the completeness of alteration. Such residual clays, when white-burning, are called kaolins. Kaolin—a rock—should be carefully distinguished from kaolinite—a mineral. Ries[1] has summarized the theories of the origin of kaolins.

2. TRANSPORTED DEPOSITS

(a) *Marine deposits.*—Sedimentation in the deep sea produces this type of clay, and the circumstances of its formation tend toward great lateral extent as compared with thickness. At its edge the clay body may show a gradation into limestone or sandstone. Vertically, also, there may be such gradations, and, in addition, there is likely to be an alternation with these rocks, which are consequently the chief impurities to be expected. The Decorah shale is a good illustration in Minnesota. Subsequent deposition of concretions may add to the impurities. Under favorable conditions impurities may be leached out. If later marine formations cover the clay deeply, the pressure they exert may consolidate the clays into shales. Where the shales are exposed by erosion, they weather again into soft clays.

(b) *Lake clays.*—These originate by much the same processes as the marine clays, but the clay bodies are generally less extensive.

(c) *Alluvial clays.*—Rivers which carry large amounts of fine sediment always vary in the rapidity of their currents in different parts of their channels. Wherever an eddy or other irregularity occurs which reduces the current very greatly, sandy clays are likely to be deposited. These conditions are most prominent along the wide flood plains of the larger streams, and are illustrated by the deposits along the Minnesota River.

(d) *Glacial clays.*—The glacial drift, as carried by the ice, has only a small proportion of clay, but, as modified by the action of water from the melting ice, this small proportion of clay may be concentrated into valuable deposits. It sometimes happens that the abrasive action of the ice grinds up a considerable mass of rock to a fine powder without any extensive decomposition. This so-called rock flour has many of the properties of clay and has been used as a brick material, but where used in Minnesota it is evident that decomposition has turned some of the minerals into kaolinite. Many lake and alluvial clays of glacial origin resemble the lake and alluvial clays not connected with glacial action, but they are of sufficient importance and extent in Minnesota to warrant separate treatment.

[1] Ries, H., The origin of kaolins: Trans. Am. Cer. Soc., Vol. 13, p. 73.

3. SLATES

Great accumulations of clay in the older formations of Minnesota have been so deeply buried and so intensely altered as to change their mineral composition and physical properties. These are classed as metamorphic slates.

RELATION OF TYPES

These various types of clay as described from a geologic standpoint are not always easily distinguished in the hand specimen or even in the field. Even the fundamental genetic distinctions between residual and transported clays are often difficult to apply, and there are prominent gradations between the several classes. The type of origin, as here outlined, bears no traceable relation to the applicability of the clay as ceramic material. One marine shale may be good fire clay and another, a fusible slip clay, without any possible distinction in the mode of formation.

CHEMISTRY OF CLAY

The following elements and oxides are usually reported as chemical constituents of clay.

Silica, SiO_2, is an essential part of the chief mineral, kaolinite, and is present in several associated minerals. It exists abundantly uncombined in the sand of sandy clays.

Alumina, Al_2O_3, is a second essential oxide of kaolinite, present also in a few other minerals.

Combined water, H_2O, is a third essential oxide of kaolinite.

Moisture is usually present in clays in large amounts, although this is not always apparent to the eye.

Iron minerals.—The oxides and sulphides are common constituents of clay, but, as they are entirely absent from some clays and seriously affect the fusibility and general behavior of the clay that contains them, they are classed as impurities, though not necessarily undesirable. Iron oxide gives red bricks their color.

Calcium is very common in clays as the carbonate and is often present as the sulphate. It has a tendency to counteract the color of iron oxide when clay is burned. Its effect on the manner of fusion of a clay is frequently disastrous, as the bricks melt suddenly and at low temperatures. Especially bad for the clay are lumps of limestone, calcium carbonate, which burn to lime and later slake and swell with such force as to burst the brick. For these and other injurious effects, calcium is classed as an impurity.

Magnesia is similar to lime, but not as injurious.

Alkalies, soda and potash, are found in most clays and are not undesirable, except for fire clays, where they lower the point of fusion.

Miscellaneous elements include sulphur, and the oxides of titanium, copper, manganese, and phosphorus, and various carbon compounds.

STATE OF MINERAL COMBINATION

The elements mentioned above behave differently depending on their state of combination, i. e., on the minerals which are present in the clay. The minerals observed in the clays of this State are: kaolinite and related aluminum silicates; pyrite, bauxite, quartz, hematite, limonite, calcite, dolomite, siderite, hornblende, micas, gypsum, feldspars, chlorite, rutile, and glauconite. Other minerals often found and likely to be present are the oxides of manganese, alum, epsomite, zeolites, etc.

No systematic classification has been devised to indicate the minerals or elements present, but the terms calcareous or ferruginous clays may be used to indicate the presence of lime or iron.

Rational analyses are attempts to determine the proportion of the common minerals present in clay, but are valuable only for those clays that contain few minerals. No method is devised to separate and estimate such a list of minerals as occur in common clay.

Chemical analyses are of relatively small importance in judging the value of clay, for in general the results of simple, physical tests are more applicable to technical problems.

CHAPTER II

THE PHYSICAL PROPERTIES OF CLAYS

With all the different materials which make up clays, mixed in an infinite variety of proportions, it is to be expected that there will be a great range in the behavior and the applicability of clays. Some of the qualities of these mixtures are extremely important and are the very foundation of most of their uses. They may be tabulated as follows:

1. Plasticity when wet.
2. Shrinkage when drying.
3. Tensile strength when dry.
4. Behavior when heated (varying widely).
   Temperature of fusion.
   Rate of vitrification (temperature range).
   Shrinkage and loss of volatile parts.
   Color and toughness (strength and hardness) of product.
5. Miscellaneous properties, such as slaking, bonding power, specific gravity, porosity, fineness, feel, odor, taste, homogeneity.

1. PLASTICITY WHEN WET

By plasticity is meant the ability to be molded, and strength to retain the molded form. This property involves the change of form without rupture and at the same time such strength and solidity that when complex forms are built up they may be self-supporting. By virtue of the plasticity of a clay it receives and retains the forms required for great building blocks; at the same time it may preserve the finest lines of the artist's tool.

Unfortunately there is no simple means of determining with accuracy the degree of plasticity shown by clays. But any one who has handled a great variety of clays can quite readily tell whether a clay is of high or low plasticity, and even go farther and distinguish different kinds, as well as different degrees, of plasticity. For example, some clays run smoothly through a die and some will drag at the corners; some are "rubbery" and some waxy. These minor variations, though hard to express, are readily felt by the expert, and the uses of the clay may be in part affected by them. It is common to speak of clays as very plastic ("fat" and "rich"), or "non-plastic" ("lean" and "poor").

In practice, if a clay is too plastic, non-plastic material, usually sand or burnt clay (grog), is added. The preheating work of Bleininger is

worthy of consideration and is discussed below under the heading of Effects of Heat. If too lean, a highly plastic clay is added. This is not always satisfactory. If a plastic clay is not refractory, it cannot be added to a lean fire clay without injuring its refractory character. For these reasons other methods for improving plasticity have been sought. Fine grinding may have a beneficial effect. A common method of increasing plasticity is to leave the clay exposed to weather and frost for a season. The exact nature of the effect is uncertain, probably both fineness and the proportion of colloid matter being affected. A third resort is the addition of ammonia or organic colloids, like tannin, or any other solution which by experiment can be shown to give the desired result.

In tempering a clay, water is usually added according to the judgment of the worker. Some clays as dug from the pit are found to be of proper consistency. Various clays and various processes of molding require different proportions of water. The percentage which is present in a clay when at about the consistency to be molded by hand is often called the "water required" or the "water of plasticity." It varies with the judgment of the operator, but is usually reported, as a large amount is an indication of a tendency to crack on drying.

2. SHRINKAGE ON DRYING

There is a strong attraction between clay grains and water. This is so great that in the plastic clay it is usually assumed that there is a film of water on all sides of the clay grain. The drying of such a clay would naturally have an effect on the size of the mass. The outer part of the plastic mass, being exposed to air, gives up its water, and the space between grains either decreases, resulting in a contraction of the mass, or remains open, while air takes the place of water. However, under ordinary conditions the attraction of clay for water causes a readjustment of the water from the interior of the plastic mass. Capillarity draws water from the center toward the drier outside and the lubricating action of the water allows a slight readjustment in the whole mass. As a total result there is the same amount of clay with a smaller amount of water, the films having become thinner throughout without any great change in arrangement. The process may be continued until the clay grains are no longer well lubricated. When the clay grains are actually in contact, the removal of water can no longer bring them closer, but there remains some water in the pores which will gradually be taken into the air and be replaced by air. Shrinkage may be measured as volume or linear shrinkage. It is usually assumed that one may be calculated from the other on the basis of volumes being proportional to the cubes of lines, but this is not always true, as a flat plate of wet clay will dry more rapidly from

the large surfaces than from the edges, and the greater part of the shrinkage will be at right angles to the flat surface. Shrinkage varies from 1 to 20 per cent linear measure, and 3 to 45 per cent volume measure.

In the arts the shrinkage of clay is very important. If brick or china ware of certain size is required, allowance must be made by making the molded form just enough larger than the required size. If large masses of clay must be dried or if shrinkage is great, there is often danger that the outside will dry and shrink before there can be the internal readjustment mentioned above. The rate of capillary flow varies with the fineness and distance and other factors. If cracks form, or the shape is badly distorted and warped, the mass is injured if not entirely ruined. The phenomenon is identical with the formation of mud cracks on the surface of a muddy field. In the arts the process is called "checking." If the shrinkage is great, masses the size of common brick must be dried slowly and with great care to avoid cracking. Many clays of good quality in other respects are now neglected because they check so badly. Such clays are often spoken of as "joint clays." They are usually highly plastic and require much water to develop the plasticity. There is, however, no constant relation between shrinkage and plasticity. The sandy clays and flint fire clays and kaolins show little shrinkage. The accepted remedy for checking is the addition of just such material as corrects excess plasticity, viz., sand or grog (burnt clay) or other non-plastic material.

3. TENSILE STRENGTH

Tensile strength is usually spoken of as the measure of the strength of dry clay. The strength of wet clays is not tested except in connection with plasticity. Probably a more useful test would be a measure of crushing strength, as the clay ware is more often subjected to pressure than to tension in building the kilns, but usually a clay of good tensile strength is strong enough, and the test is more easily made by following roughly the standard methods of testing cement. The tensile strength of clays varies from 30 to 350 pounds per square inch; 100 is enough for most purposes. From the plastic state to the dried state the tensile strength increases continuously. Clay grains, originally separated by films of water, have been left in intimate contact by the evaporation of that water and at last adhere to each other strongly. The gluelike nature of any colloids that may have been in solution also manifests itself as the water is removed.

4. EFFECTS OF HEAT

These are so complex that the subject must be subdivided. In outline the effects are:

A. Plasticity, tensile strength, and shrinkage are decreased by slight heating.
B. A series of volatile products are given off.
C. Important reactions take place.
D. Fusion occurs, in a progressive manner, to be studied at several stages.
E. Quality of the product, including colors, shrinkage, toughness, hardness, strength, etc.

A. EFFECT OF PREHEATING

Bleininger,[1] at the Bureau of Standards, has made an exhaustive study of the effects of temperature up to 400° C., in the hope of correcting the defects of "joint" clays, those which check or crack badly in drying. His results show that between 250° and 300° C., there are changes in most clays, chiefly a decrease in shrinkage, plasticity, and the amount of water required. Subject to various limitations for which reference must be made to the original, where they are clearly discussed, the method offers very valuable commercial possibilities in Minnesota, since there are immense bodies of joint clay in the Red River Valley—Lake Agassiz silt.

B. LOSS OF VOLATILE MATTERS IN HEATING CLAYS

The hygroscopic moisture is usually almost completely removed from the clay ware before it is placed in a kiln for firing. During firing a series of products is removed, depending somewhat on the impurities present. The most prominent constituents driven out are water, hydrocarbons, carbon dioxide, and sulphur, and they require different degrees of heat for their removal. Oxygen may be given off or taken into the clay as a result of conditions of firing.

The result at red heat is an increase in porosity without much change in the size or strength of the ware. A too rapid increase of temperature and evolution of these gases may break the clay mass, with explosive violence, even injuring the ware near by. Snapping of this sort is seldom troublesome if care is used in removing water. The burning of the organic matter produces heat, like the addition of more fuel, and may cause a sudden rise in temperature when not desired. Normal colors at this time are red, for clays containing iron. At a temperature only a little higher, the carbonates, chiefly that of calcium, begin to give off carbon dioxide and leave a chemically active lime residue in the clay. Sulphur may be evolved and oxidized from sulphides like pyrite at low temperatures, but it will not be evolved from sulphates like gypsum until very high temperatures are reached. If fusion begins before all these

[1]Bleininger, A. V., Preheating of clay: Bull. Bur. St., Vol. 7, No. 2, 1910.

gases are evolved, the clay mass will swell and become vesicular or "blebby," and be ruined.

C. CHEMICAL REACTIONS

Aside from the reactions mentioned, yielding volatile constituents, there is a complex condition as regards oxidation and reduction, depending on the supply of fuel and air, and, as the temperature of the kiln rises, reaching the fusion point of some compound present in the clay, reactions of various sorts occur. The teachings of physical chemistry also make it clear that reactions may occur producing a liquid from two solids which are in contact even if the temperature is not high enough to melt either. The familiar example is a mixture of ice and salt, which is liquid below freezing temperature. In clays, lime and silica are examples of such substances. The fused material later acts as a solvent, in which other minerals are absorbed, and at this high temperature in fluid or semi-fluid condition is chemically more active than before. As silica is the chief acid present, the main products are silicates usually of indefinite mixed composition. After the firing the solidification of these melted parts of the clay yields the rocklike quality of the finished ware. These melted silicates form the cementing material between the more solid grains. They are largely responsible for the character of the final product.

D. FUSION

The formation of the fused silicates above discussed does not take place instantaneously, but progresses as the temperature increases. The first liquid to form, if kept at the temperature of formation, may dissolve a considerable portion of the surrounding material without itself becoming less fusible. If the temperature is raised, other minerals and combinations reach the point of fusion, and other materials are dissolved in the melt.

The effect on the clay is, therefore, to be studied as a progressive matter, not as a sudden change of conditions from solid to liquid. Three stages are usually noted. The "temperature of fusion" is usually that of viscosity under no load. Fusion under load[1] is a test applied only to refractory clays.

I. At incipient fusion only a few minerals and combinations have fused. If the fused parts are abundant, the whole mass will cool to a product that cannot be scratched with a knife, so that the hardness of the product is the common sign of incipient fusion. This degree of fusion

[1]Bleininger, A. V., and Brown, G. H., The effect of heating fire clays under load conditions: Trans. Am. Cer. Soc., Vol. 12, p. 337.

causes very little shrinkage. Common brick usually require no further heat. Fire clays are not often burned even to this stage.

II. At vitrification enough of the clay has fused so that pores between unfused grains are nearly all filled, but the unfused portion still is abundant and the fused portion is so viscous a liquid that the ware keeps its shape. Shrinkage is usually high. A large amount of high-grade ware is burned to vitrification, or very near it. Porcelain and chinaware, roofing tile, paving and foundation brick, and sanitary ware, are usually vitrified, and some of them are also glazed. This makes the ware impervious to water. Many vitrified bricks are used also as building brick since they are durable and resistant, and many of them have a fine color.

III. At the point of viscosity the unfused particles in the clay are surrounded and suspended in the fused and liquid portion, and the brick flows, destroying the original form. When brick have been piled in a kiln and burned to the approach of viscosity, they may stick together, and, if deformation is not too great, the breaking up of the resulting mass may give blocks of about the size and shape of brick with the rough irregular fracture of broken stone. Such brick can be used in producing many artistic effects and have become quite popular as "klinker brick." The actual temperature of viscosity, commonly noted as the fusion temperature, ranges widely.

Range of vitrification.—Most important in testing a clay to find its applicability to different processes of manufacture is the range in temperature from incipient fusion to viscosity. In firing a kiln full of clay ware the combustion chambers cannot be so distributed as to give an absolutely uniform temperature throughout. Well-made, expensive kilns can approach closely to that uniformity, but there is always likely to be a variation of a few degrees. If it was desired to fire a brick to vitrification at 1200° C., it would be likely that the top or bottom courses would reach only 1160° and the brick nearest the fire might reach 1240°. If the point of incipient fusion was only 40° below the point of vitrification, the underburned brick would not be salable. But if the incipient fusion was 100° to 200° below vitrification, there would be every reason to expect that all the brick fired to within 40° of the point of vitrification would be so nearly vitrified that they would be entirely satisfactory. On the other hand, if viscosity was reached at 1240°, the brick near the fire would be waste, while if not reached for 200° after vitrification, the brick burned to 1240° would no doubt be of good quality. The losses due to underburning and overburning may be as high as 30 per cent of the kiln.

The importance of this determination of the range of temperature

during fusion has led to a careful study by R. C. Purdy[1] resulting in recommendations for tests of porosity and specific gravity as a measure of vitrification. The diagrams (Figs. 8, 9, 10, and 11) give a general idea of the method used in distinguishing the applicability of a clay from its behavior. By firing bricklets of clay to several different temperatures and determining their porosities, a curve can be drawn to show the rate of vitrification. The position of this curve as compared with Purdy's diagram, will indicate the applicability of the clay. (See Chapter V.) Much more commonly one judges the behavior of a clay by simple inspection of the bricklets burned to several different stages. A knife will easily show whether the clay has been burned so that it cools to a hard product—to the temperature of incipient fusion. The stage at which viscosity is reached is shown by the deformation of the bricklet. If these are widely separated in temperature, the clay can be safely vitrified. The temperatures to which common clay wares are burned are shown in the following table, in terms of Seger cones.[2]

[1]Purdy, R. C., Paving brick clays of Illinois: Illinois Geol. Sur., Bul. 9, pp. 277-8.
[2]Seger cones are small cones of clay and salts mixed so that they soften or collapse at definite temperatures.

SEGER CONES

	Fusion Point			Fusion Point	
No. of Cone.	Cent.	Fahr.	No. of Cone.	Cent.	Fahr.
022	590	1094	8	1290	2354
021	620	1148	9	1310	2390
020	650	1202	10	1330	2426
019	680	1256	11	1350	2462
018	710	1310	12	1370	2498
017	740	1364	13	1390	2534
016	770	1418	14	1410	2570
015	800	1472	15	1430	2606
014	830	1526	16	1450	2642
013	860	1580	17	1470	2678
012	890	1634	18	1490	2714
011	920	1688	19	1510	2750
010	950	1742	20	1530	2786
09	970	1778	21	1550	2822
08	990	1814	22	1570	2858
07	1010	1850	23	1590	2894
06	1030	1886	24	1610	2930
05	1050	1922	25	1630	2966
04	1070	1958	26	1650	3002
03	1090	1994	27	1670	3038
02	1110	2030	28	1690	3074
01	1130	2066	29	1710	3110
1	1150	2102	30	1730	3146
2	1170	2138	31	1750	3182
3	1190	2174	32	1770	3218
4	1210	2210	33	1790	3254
5	1230	2246	34	1810	3290
6	1250	2282	35	1830	3326
7	1270	2318	36	1850	3362

Common brick	Cone 012—01
Hard burned common brick	1— 2
Buff face brick	5— 9
Fire proofing	03— 1
Terra cotta	02— 8
White earthen ware	8— 9
Fire brick	5—14
Porcelain	11—13
Sewer pipe	3— 7

E. QUALITY OF THE PRODUCT

After cooling from the heat treatment the quality of the product can be tested in various ways. The various steps in the process of heating have important effects. *Color* will be due largely to the presence of iron, or sometimes to manganese, but in the firing it will be modified by the oxidizing or reducing gases and by the degree and temperature of vitrification. *Shrinkage* becomes notable at the beginning of fusion, is complete at thorough vitrification, and is followed by swelling in some cases if gases are evolved after the formation of much glass. The *hardness, strength,* and *toughness* are all low until the fusion begins; then the quantity of glassy cement becomes the controlling factor; at vitrification the *character of the glassy cement* becomes the dominant factor. The hardness of burned clay is usually tested by comparison with tempered steel.

MISCELLANEOUS PHYSICAL PROPERTIES

The slaking of a clay is the tendency of a dry lump to absorb water and fall to pieces when immersed. Clays which slake promptly are easily rendered plastic without fine grinding.

The bonding power of a clay is its ability to hold in suspension less plastic material and to render the whole mass plastic and strong. It is usually, but not always, good, if plasticity is high.

The properties of specific gravity, porosity, fineness, feel, and color of raw clays have less certain connection with the uses or availability of the clays and, though there may be some relationships, no one has yet stated an exact system by which one may judge the useful properties from them. The fineness of grain probably affects the fusibility and rate of fusion of impure clays, but this is less notable in high-grade clays.[1]

Homogeneity might be considered a physical property and is of importance in the application of clays to industries, as the variable clays need more careful selection and mixing.

[1]Hofman, Trans. Am. Inst. Min. Eng., 1898.

CHAPTER III

CLASSIFICATION AND ADAPTABILITY OF CLAYS

THE BASIS OF CLASSIFICATION

Various classifications of clays have been proposed for various purposes. Commercially, the uses of the clays are the basis of names. Geologically, the origin is important. Technically, the physical properties of the clay are most distinctive.

CLASSIFICATION BY USES

The uses of clay are listed by H. Ries as follows:[1]

Domestic.—Porcelain, white earthenware, stoneware, yellow ware and Rockingham ware for table service and for cooking; majolica stoves; polishing brick, bath brick, fire kindlers.

Structural.—Brick: common, front, pressed, ornamental, hollow, glazed; adobe; terra cotta; roofing tile; glazed and encaustic tile; drain tile; paving brick; chimney flues; chimney pots; door knobs; fire-proofing; terra cotta lumber; copings; fence posts.

Hygienic.—Urinals, closet bowls, sinks, washtubs, bathtubs, pitchers, sewer pipe, ventilating flues, foundation blocks, vitrified bricks.

Decorative.—Ornamental pottery, terra cotta, majolica, garden furniture, tombstones.

Minor uses.—Food adulterant; paint fillers; paper filling; electric insulators; pumps; fulling cloth; scouring soap; packing for horses' feet; chemical apparatus; condensing worms; ink bottles; ultramarine manufacture; emery wheels; playing marbles; battery cups; pins, stilts, and spurs for potters' use; shuttle eyes and thread guides; smoking pipes; umbrella stands; pedestals; filter tubes; caster wheels; pump wheels; electrical porcelain; foot rules; plaster; alum.

Refractory wares.—Crucibles and other assaying apparatus; gas retorts; fire bricks; glass pots; blocks for tank furnaces; saggars; stove and furnace bricks; blocks for fire boxes; tuyeres; cupola bricks; mold linings for steel castings.

Engineering works.—Puddle; Portland cement; railroad ballast; water conduits; turbine wheels; electrical conduits; road metal.

Of these, the uses of sufficient importance to give variety names to clays are:

Class Names on the Basis of Uses

Fire clay	Brick clay	Paper clay
Slip clay	Glasspot clay	Tile clay
Stoneware clay	Paving brick clay	Sewer pipe clay
Saggar clay	Paint clay	Pottery clay
Terra cotta clay	Adobe clay	China clay

These terms are rarely used in a restricted sense. The same term may be applied to widely different clays. Different terms may be applied to similar clays. It is hoped that they will be used less as the properties of the clays are better known.

[1]Ries, H., and Kümmel, H. B., Clays and clay industry of New Jersey; Final Report of State Geologist, Vol. 6, pp. 213-4.

CLASSIFICATION BY GEOLOGIC ORIGIN

In the discussion of geologic processes the following classes may be mentioned:

Class Names Based on Geologic Origin

I. Residual
  a. From igneous and metaphorphic rocks
  b. From sediments
II. Colluvial
III. Transported
  a. Marine
  b. Estuarine
  c. Lacustrine
  d. Alluvial, flood plains and terraces
  e. Glacial
    1. Till
    2. Lacustrine
    3. Alluvial
    4. Loess
IV. Metamorphosed slates

CLASSIFICATION BY PHYSICAL PROPERTIES

In the classification on the basis of physical properties, it is desirable to select the most important of the properties for first divisions and the less important ones for subdivisions. Of the physical properties discussed above, plasticity, strength, and behavior in the fire are most noteworthy, and of these the fusion phenomena are fundamental. If the plasticity or strength are not satisfactory, the deficiencies may be corrected by additions of suitable proportions of other clays. If the range of vitrification is too small, it is very difficult to make a proper addition to correct it.

Class Names Based on Physical Properties			*Main Uses*
I. Refractory (above cone 27)	Earthy, usually residual, non-plastic		China clay
	Plastic		Ball clay
	Flint-like, non-plastic		Fire clay
II. Semi-refractory (above cone 10)	Safely vitrifying	red burning	Sewer pipe Paving brick
		buff or cream burning	Stoneware
	Rapidly fusing		Low grade fire clay
III. Non-refractory (below cone 10)	Safely vitrifying	red burning	Drain tile Foundation brick
		buff or cream burning	Vitrified brick Foundation and sewer brick
	Rapidly fusing		Common brick

Subdivisions of II and III may be made on the basis of degree of plasticity, or some other physical character.

RELATION OF PHYSICAL PROPERTIES TO USES

Common brick clays should be fairly plastic and should burn hard below cone 1 (2100° F.). The product should have a pleasing color. Higher plasticity is required for stiff-mud than for soft-mud brick.

Clay for front brick should be somewhat more plastic so that the brick may hold their form better and present smooth surfaces and square corners. The color after burning is a more important matter in this case. Such brick are nearly always burned so hard that they cannot be scratched with a knife. They should have a good range of vitrification to avoid heavy losses from deformed brick.

Brick with a glazed surface, allowing the original color to show through, or with an enamel, an opaque coating, with its own color, need not be very different from common brick, if the fused coating is so adjusted as to expand and contract with the body of the brick. If the expansion of the body is different from that of the surface, the two would crack away from each other on cooling.

Hollow brick and *fire-proofing blocks* are made to secure lightness in weight. Other properties being equally good, the lighter and more porous product is the more desirable. The clay must be plastic enough to work in an auger machine with a die for the hollow center. Often, if the bonding power is good, it is desirable to add sawdust to increase the porosity. The dried clay must have moderate tensile strength. The burned color is immaterial, but the red blocks are usually ferruginous and somewhat heavier than the lighter colored ones. The burning must produce strength and durability in the product, rather than hardness, density, or beauty.[1]

Clay products to withstand temperature changes when wet.—Foundation brick, sewer brick, and sidewalk brick, all of which are often subject to frost, differ from common brick only in the degree of vitrification. These must be so well vitrified that water cannot enter in such a way as to disrupt the brick on freezing. It should be possible to vitrify the clay almost completely—to a porosity of only 4 or 5 per cent—without leaving many soft brick or many viscous deformed brick in the kiln.

Paving bricks and blocks require the same kinds of material as foundation, sewer, and sidewalk brick, but with the additional quality of toughness of the product. This is even more important than completeness of vitrification. From some clays the toughest brick are obtained by stopping the heat before vitrification is complete. There is no way to foretell from the composition and raw properties of the

[1]Specifications have been formulated and can be found in Eng. News, Vol. 47, p. 248.

clay whether or not it will yield a tough product. It is necessary to try them, in actual practice, by several methods.

The clays for drain tile are similar to those used in making stiff-mud brick. The form of a tile is such that there is a strong tendency to warp and crack in drying. If the molded form does not warp on drying and does not show auger laminations, it will probably make good drain tile.[1]

Wall and floor tile should be made from clays similar to those used for hard paving bricks, and, in addition, the product should have a pleasing color.

Terra cotta clay must be very highly plastic and very strong to retain the complex ornamental designs imposed upon it. The clay is usually selected with great care to obtain uniform color and a strong product free from cracks. The clay should have a good range of vitrification, but usually is not burned very hard.

Clay for sewer pipe must be much like that for paving bricks. The product is not subject to the same severe abrasion, but the forms are so large and thin-walled that high strength is a necessity. Only a small amount of shrinkage is allowable, as warping and cracking are fatal defects. A dark colored product, usually obtained by a salt glaze, is demanded by the market.

Clay for porcelain, pottery, china, and other domestic and sanitary ware, requires the highest degree of preparation and control. It must be plastic and free from sand. As a rule it is washed to remove impurities. It must be strong to hold its shape and it must not shrink so much that it warps. It must burn white, or very light, and partially vitrify without danger of losing its form. The range should be over 200° F. The product should be tough and strong. When a glaze is to be applied, the thermal expansion should be the same as that of the glaze, to prevent cracking.

Refractory clays must primarily stand at high temperatures in the structure desired, and sometimes they are subjected to repeated heating and cooling without losing their strength and infusibility. Many of the refractory clays are non-plastic, and ordinarily one does not expect high plasticity or much strength of the product. But if these are too weak, additions of plastic clay or bonding material must be made even at the expense of fusibility. In some furnaces ware with very coarse grain and open texture is wanted in order to prevent rapid conduction of heat. Such ware is formed by the addition of large amounts of crushed burned clay—grog. In other furnaces clay is desired which burns to a very

[1]Tests for good drain tile have been formulated by the Am. Soc. Testing Materials. Proceedings, Vol. 11, p. 838.

strong dense body at medium temperature, but does not weaken or soften until a very high temperature is reached.

Slip clays must primarily melt to a smooth glaze at a temperature lower than that of the body on which they are to be used, and must be fine grained so as to remain suspended in water indefinitely.

METHODS OF TESTING CLAYS

In estimating the availability of a clay the procedure is as outlined below. The reports contributed by the U. S. Bureau of Standards were obtained by similar methods.

1. *The working quality* is determined by dropping a lump of dry clay into water to determine whether it slakes at once. Bricklets were molded by machine or by hand presses; shrinkage was estimated from the volumes before and after drying. The need of care in drying was estimated from the strength of the briquettes dried slowly and those dried rapidly. Mr. F. M. Handy has developed also, in connection with this work, a test of adhesion to show the danger of defective structure, if the clay is molded in a stiff-mud machine. (See Plate II A.)

2. *The behavior in firing* was tested in a large kiln with several bricks fired to different temperatures. (See Fig. 3.) Color, hardness,

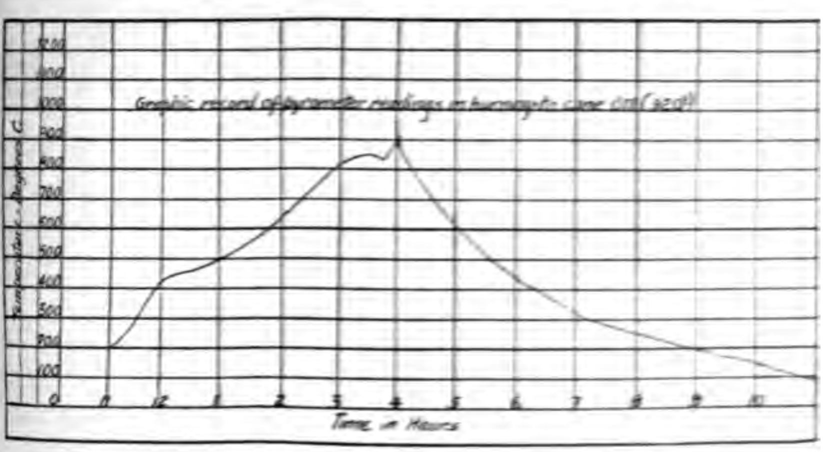

FIGURE 3. TIME-TEMPERATURE CURVE OBTAINED IN BURNING TESTS (REPORTED HEREIN).

and porosity were noted after firing. Hardness was tested by comparison with Mohs' scale, and the brick are said to be "steel hard" or have a hardness of 6, when they cannot be scratched with a knife. Most important of the characters is the range between the temperature where the clay begins to vitrify and the temperature where so much has melted that the brick loses its shape. This range of vitrification determines

whether or not a clay may be burned to a hard product successfully, for if a clay becomes viscous at a few degrees above the temperature where it begins to fuse, it is almost impossible for the entire kiln to reach the point of incipient vitrification before some of the brick have melted.

3. *Special tests.*—Refractory clays were tested in a Meeker Muffle, and some impure clays were washed, as nearly as possible by the methods commercially successful. A few analyses were made. Slip clays were applied to a semi-refractory clay after preliminary firing. Tests of fineness were conducted on a few clays with a series of sieves.

4. *Tests of clay products* made in Minnesota were confined to brick and hollow tile. Transverse tests were made on thoroughly dry brick and modulus of rupture calculated by the usual formula. Absorption tests were made by weighing the brick first when thoroughly dry, and later after they had been boiled in water four hours. Crushing tests were made on five wet and five dry bricks.

CHAPTER IV

TECHNOLOGY OF CLAYS

PROSPECTING

THE USUAL METHOD OF PROSPECTING

Most developed deposits of clay have been found by men in other pursuits, who had the requisite knowledge and skill to observe the signs about them and investigate what others would pass by unheeding. One who has become familiar with the appearance of one clay will recognize a similar material elsewhere. A plowed field, an excavation along a road, a well, a post hole, or the bank of a stream, may reveal valuable clays. Most common clays lie near the surface and may be found by examining any place where the soil has been removed. If there are no such places, a dirt auger with an extension handle is the simplest means of making excavations. Some clays, however, do not lie so near the surface and are not so easily discovered. Yet if they are fire clays, or kaolins, it may still be worth while to develop the deposit if it can be discovered. Other methods of prospecting are useful.

THE METHOD OF STRATIGRAPHY

The method of stratigraphy has for its foundation an assumption which is fairly reliable, if used with caution. Where sedimentary formations lie in nearly horizontal layers, it may often be assumed that they are continuous underground, even if the soil and vegetation have accumulated so that the rock is concealed. The logic may be illustrated by an example in Minnesota. The rock formations of southeastern Minnesota, where well exposed, at many places show bluffs at the top of which is a limestone containing such fossils that it is identified as the Galena. Below it come in order the Decorah shale, the Plattville limestone, and the St. Peter sandstone, each with a definite thickness and character. If near Faribault, for example, there should be a number of such exposures, of uniform character, and at the particular place where it is desired to use the Decorah shale no outcrop occurred except the Galena, it would be safe to conclude that under the surface the Decorah exists as it does in other parts of the neighborhood. (See Fig. 4.) This assumption is useful in finding some clays. A line of springs along a hillside also often gives evidence of clays underground.

More rarely, when conditions seem to warrant it, drill holes and shafts are sunk to considerable depths in search of clays.

WHERE TO PROSPECT

Common clays are so widely distributed in Minnesota and in most other states that the choice of a deposit depends principally on the marketing conditions. To be valuable, clays must be near a market or near some line of easy transportation. Some very excellent clays in this State are destined to remain untouched for years because they are too inaccessible. At the present time it will not pay to haul fire clay or pottery clay by wagon to any distant railroad point for shipping. The price last year for good fire clay placed on the car was about $1.25 per ton, and a wagon haul would consume any profit at that price.

In connection with the market and commercial considerations, the cost of labor, fuel, and other material should be considered. A few high grade clays may overcome the handicap of unfavorable market conditions.

WHAT TO DETERMINE

After studying market conditions and finding a clay, before a plant is erected one should determine, first, the amount and distribution of clay; second, its general character; third, the conditions of working; and, if all these are favorable, finally, the purposes for which the clay is suited. Each of these deserves the most careful attention.

LOCATION OF PLANT

The exact location of the buildings and yards with respect to the clay pit is a matter which deserves more attention than is usually given it. In examining a large number of clay deposits, one cannot but be impressed by the numerous examples of yards and buildings which have been built over the best clay in the deposit. The plant should be arranged so that the material progresses from pit to machine, to drying racks, to kiln, and to shipping point, in regular sequence, without any great distance between points, and without a return over ground once passed.

WINNING THE CLAY

Open pits are most common. Underground work is too expensive except for kaolin and fire clays. The pick and shovel are used on most clays. With uniform clays requiring no selection in the pit, a plow and scraper are often used, and in large plants the steam shovel is most economical. Any overburden is removed by similar methods. Drainage is an item of expense in some places.

TRANSPORTATION

Only the most valuable clays of Minnesota are shipped by rail to the

A. A BURNED BRICK SHOWING AUGER LAMINATION.
A BURNED BRICK SHOWING EFFECT OF PEBBLES.

B. SLATE AT THOMPSON, SHOWING BOTH CLEAVAGE AND BEDDING.

plant. A cable car is much the most common method of bringing the clay to the machine.

PREPARATION

Some clays are sent directly from the pit to a machine for mixing and molding, but a rather large number are improved by some preliminary process. Plasticity may be improved if the clay is weathered. Many clays cannot be worked until crushed and ground; and often with the grinding, the clay is passed over screens to remove the larger pebbles. High grade clays are often washed to remove some coloring matter and sand. If clays are to be mixed or if additions are to be made for changing the color or character of the clay, the work is usually done before tempering. The pre-heating referred to in the chapter on Physical Properties is recommended for those clays that crack on drying. The tempering may be conducted in plain soak pits dug near the machine, in more elaborate ring pits, in wet pans, or in pug mills. In the manufacture of pottery more care is needed and the process is closely controlled by the individual worker. The washing and molding processes in use at Red Wing are described in the report on Goodhue County.

THE HUTCHINSON PROCESS FOR PEBBLY CLAYS

The gray drift which is so widespread over Minnesota requires a cleansing treatment before it can be used for the manufacture of high grade ware. The limestone pebbles are causes of the chief defects. After the clay is burned, the limestone particles slake, swell, and destroy the brick. There are several ways in which a clay containing such pebbles can be made useful. First, if the limestone is not too abundant, fine grinding may be sufficient to remedy the defect. Second, by fairly fine grinding, and immersing in water, after removal from the kiln, the lime is rendered harmless.[1] Third, by drying and gently grinding, so that the clay is disintegrated and the harder pebbles left, it is possible to catch most of the limestone on a screen, through which the clay passes. Fourth, by using machines for removing pebbles from a clay in a plastic condition.[2] Fifth, and most important, is a washing process. This process is emphasized because a plant in Minnesota, using material that can be found in nearly every part of the State, has made a commercial success of the process.

At Hutchinson, in McLeod County, the gray drift is cleansed of limestone pebbles by a process that is probably not duplicated in America. This process has been developed by Mr. M. C. Madsen, who has

[1]Binns, C. F., Trans. Am. Cer. Soc., Vol. 14, p. 218.
[2]The Diesner clay cleanser: Brick, Vol. 31, No. 5.

been experimenting on it for many years. The actual machinery of washing is comprised in a space not over 20 feet square and 15 feet high, and washes 130 yards of clay in a day. The clay from the bank is hauled by cable car to the washer. Here it is mixed with an excess of water and agitated by a series of vertical rods fastened to a rotating cross beam. The harrow-like motion of these rods has a tendency to throw the larger pebbles toward the center of the washer, while the fine clay and sand remain suspended and distributed throughout the pit. Near the center of the pit a bucket elevator of continuous operation dips into the pit and removes the gravel. At the sides of the pit an opening covered with a screen of the proper mesh allows the escape of the fine sand and clay. These are conducted to one of the series of open ponds in which they are allowed to settle. After a time some of the water may be pumped off and the rest is left to sink into the ground. The sand naturally settles close to the intake of the pond and the clay is carried to the farther side of the pond. After partial drying it is ready to be taken to the stiff-mud machine where the clay and sand are mixed in approximately the same proportions in which they existed in the drift before the washing. The gravel is sold for concrete. Both the clay and sand contain a considerable amount of calcium carbonate, but, if care is taken that the coarser sand is removed, no damage is done by the impurity, and it is certainly less abundant than in the unwashed drift. The plant at Hutchinson makes use of three round down-draft kilns, and plans are made to double the capacity. It has been found possible with this clay to produce a very good drain tile and hollow building block, so that the production of common brick has become a secondary matter. The drain tile are of excellent quality and are famous for their ability to withstand freezing.

A large plant of this character, shipping its product over a large territory, would meet competition with plants using clay free from limestone pebbles, and, therefore, more cheaply worked. For a local plant of medium size, however, there is promise of success, and there is room in the western and northern parts of the State for several such plants. See the reports on Pipestone and Douglas counties.

MOLDING

Brick are molded either as very soft mud by hand or machine; or as stiff mud by an auger machine; or nearly dry by a press. Sometimes after molding and partly drying, brick are sent to a press to be improved in form and structure. A common defect in structure is shown in Plate II A. Most hollow ware is molded by a stiff-mud process. Sewer pipe are made of stiff mud, but with an intermittent press instead of a continuously acting auger.

Pottery is molded by several processes, some of it being hand molded, some turned on a wheel, some pressed in plaster molds, and some "cast" in plaster molds.

The process of glazing is sometimes conducted by adding a coating on the surface of the ware as molded, but in less valuable ware is brought about in burning by the addition of salt vapors.

DRYING

The supply of air and the temperature must be regulated usually so that the ware is not dried too fast at first. This would crack most clay ware. Many devices are made use of to regulate the rate. Brick are commonly dried in open air or under sheds, sometimes on racks. Some brick and the more complex wares are dried in tunnels with artificial heat, or in large drying rooms.

BURNING

The kilns used, fuel burned, and temperature desired are diverse. Probably nine-tenths of the bricks burned are simply piled on a level place with arched spaces left for fire at the bottom and open work enough in the body of the kiln for the heated gases to rise through. The outside layers may be piled close and plastered with mud to keep the cold air out. The fuel is often wood, though coal is used at some plants. This is a *scove kiln.* A kiln with permanent walls may be an improvement on this, but usually if a wall is built, the arrangement of fire box and chimney are altered so that the heat of the fire goes first to the top of the kiln, and, passing down through the bricks, leaves by a flue at the bottom. This is the *down draft kiln.* It may be round or oblong. Pottery is burned in kilns with arrangements for keeping the combustion gases away from the ware. The pottery is often surrounded with fire clay boxes—saggars—to keep it from contact with the flames. Gas is a desirable fuel. For economy in heat, many attempts have been made to devise *continuous kilns,* where gases passing from one combustion chamber are conducted to another to warm it up, preliminary to combustion in that chamber.

The burning process may be arbitrarily divided into three parts: (1) dehydration; (2) oxidation; (3) vitrification. Dehydration always occurs and in some clays requires considerable time. Oxidation takes place only in those clays containing iron or organic matter or both. The process of oxidation may take a large amount of time and the ware must be kept at a good red heat until it is finished, before any attempt is made to raise the temperature to the beginning of the melting process—or vitrification. For if the clay begins to melt before oxidation

is complete, the ware is almost certain to swell and puff out of shape and be discolored inside. More losses and trouble are due to mismanagement at this stage than at any other. During vitrification the clay begins to melt and the liquid formed fills the spaces between unmelted grains, reducing the porosity. Good vitrification makes a product that will be much more resistant to frost and abrasion than material not vitrified.

Minor features of burning worthy of mention are glazing, flashing, and the formation of efflorescences. Glazing is sometimes accomplished by throwing salt on the fire when the kiln is at its hottest. Flashing is a process by which the color of the products containing iron can be brightened and changed depending on the regulation of the supply of fuel and air. Efflorescences may appear on brick after burning. They are due partly to salts concentrated on the surface during drying, but partly also to the action of combustion gases in the kiln.

USE OF THE PRODUCT

The method by which a brick wall or pavement is constructed has a great deal to do with the satisfaction it gives. With drain tile, also, it is known that the method of placing the tile is an important factor in the success of drainage. The purchaser of clay brick and tile should not be content to get good wares, but should see to it that they are properly used.

The advantages of the use of clay products are fairly well known. The excellent quality of the paving brick clays and drain tile clays in this State should especially favor the use of local material for these purposes. There will undoubtedly be an increasing demand for both paving and tile.

CHAPTER V

GEOLOGY OF MINNESOTA WITH SPECIAL REFERENCE TO CLAYS[1]

PHYSIOGRAPHY

Minnesota exhibits a series of morainic belts and partially filled kettle holes, alternating with more gently undulating belts of modified glacial drift, and several large lake beds, the most notable of which are those of ancient Lake Agassiz in the northwestern part of the State and the delta deposits of the glacial Lake Superior. Rock hills rise in rounded masses through the drift in a few points, mostly in the northern part. In the extreme southeastern corner is the driftless area, occupying portions of a few counties, where outcrops are more frequent, although most of the surface has been covered by a veneer of loess from 1 to 12 feet thick, averaging about 4 or 5 feet. This loess tends to smooth over any small irregularities in the surface.

The principal drainage system is that of the Mississippi River and its intricate net of tributaries. In the northwest the Red River of the North constitutes the main drainage basin. A small area drains into Lake Superior.

GEOLOGIC HISTORY

The rocks of Minnesota range in age from the earliest Archean granites and schists to the Recent alluvium. The accompanying table, Plate VI, arranged in order of age with the oldest formations at the bottom and the youngest at the top shows the principal formations found within the State.

The oldest known formation in Minnesota is the Ely greenstone of Archean age, occurring in the northern part of the State. It is probably for the most part of igneous origin. Much of it has been metamorphosed to a schist and the remainder is so altered by pressure and folding and igneous intrusions that its original character is effectively obscured. Before the end of Archean time sedimentary rocks were deposited and intrusions of granite magmas forced their way upward. These now occur as enormous masses of granite and gneiss in the older Archean greenstones and schists. With the processes of sedimentation came the deposition of material rich in iron and processes began to operate which

[1]Credit for the main features of the discussion of the geology is freely given to N. H. Winchell and Warren Upham, Final Reports of the Minnesota Geol. and Nat. Hist. Survey. Also to C. W. Hall and O. E. Meinzer who contribute some new data on southern Minnesota in Water-Supply Paper, No. 256, U. S. Geol. Survey.

resulted in the formation of great bodies of iron ore. Many of the granite intrusions of this time were of such great extent that little of the intruded rock is now in evidence.

Following the Archean period came the deposition of a great series of sediments over most of the northern part of the State and large parts of the south. After their deposition they were metamorphosed by pressure and both acid and basic rocks were intruded. These sediments and intrusives make up the Algonkian system.

Near the close of Algonkian time, the basic Keweenawan rocks were erupted mainly as an immense series of flows. This igneous activity was followed by further sedimentation and erosion until Paleozoic time, when, with the advance of the sea, conditions became favorable to the formation of sandstones, limestones, and shales. These covered most of the State except the northern and northeastern parts. During Paleozoic time the area emerged for a period and was then again submerged, for there is an unconformity between the Ordovician and Devonian. The close of the period is marked by a complete emergence.

Following the emergence of the land after the Devonian, there came a long period of erosion and weathering through the latter part of Paleozoic and most of Mesozoic time. The Cretaceous sea, in which all the next sediments were deposited, encroached upon the land from the west and gradually spread eastward, partially submerging the older rocks, all except the highest ridges, which extended above the sea to form islands. The rocks appear to be of Dakota or Benton age, in terms of the formations known farther west. There is here a pronounced unconformity. The Cretaceous rests directly upon the much-weathered Archean surface in many places. The conditions under which such decomposition of granite could occur must have been the long continuous weathering of a region of comparatively low relief, for had the surface been one of much relief, erosion would have removed the soft decomposition products.

After the recession of the sea in late Cretaceous time the region has not again been submerged. Much of the Cretaceous was probably eroded before the invasion of the continental ice sheets, and much more of it was removed by this glacial erosion.

PLEISTOCENE

By Frank Leverett, of the United States Geological Survey

In Minnesota the Pleistocene deposits show a peculiarly complex history, there being not only recurring stages of glaciation separated by long stages of deglaciation, but also a complexity of ice movement in a given glacial stage. There was one movement into Minnesota from the northwest, another from the north, and a third from the northeast in the

latest of the glacial stages (the Wisconsin), and possibly there was similar complexity in earlier stages. These movements were not synchronous in their advance, culmination, and waning, but instead each had its own time of waxing and waning. The interpretations of these complex conditions are incomplete as yet, and the relations of ice lobes set forth in the accompanying glacial map are at best only approximate.

(1). The oldest glacial deposit, the pre-Kansan or Nebraskan, is so completely buried beneath later deposits that it is not drawn upon in the clay industries so far as known to the writer. The attenuated edge of this drift may be exposed in the southeastern counties.

(2). Deposits of a clayey and silty character have been found in a few places at the junction of pre-Kansan and Kansan drifts which represent accumulation in the Aftonian interglacial stage. They are, however, of slight thickness and limited extent and rarely seen in either natural or artificial cuts and hence not likely to figure in the clay resources of the State.

(3). The Kansan drift is extensively exposed in the southeastern part of the State and also in part of Pipestone and Rock counties in the southwestern. It is generally of clayey texture, but seldom is sufficiently free from stones to be considered valuable in clay industries. It contains local pockets or lenses of marly pebbleless clay which may prove of value in these industries.

(4). The results of subaerial action on the Kansan drift have been of some importance to the clay industries. Through the agency of wind much of the surface in the southwestern corner of the State and part of the southeastern has become coated to a depth of several feet with loess. This pebbleless deposit, composed of fine dust that settled over these districts, has been used widely in brick and tile manufacture in other states and may be so used in this State.

(5). The Wisconsin drift so far as developed by the movement of ice from Manitoba in its course across western and southern Minnesota, is largely of clayey texture, but, like the Kansan drift, it contains usually too many small stones to be of value for brick or tile. These stones, moreover, are largely limestone and especially unfavorable constituents because of slaking in the process of manufacture of brick or tile. There are lenses and pockets of pebbleless clayey material included in the stony clay which may become of limited value locally. Furthermore, this drift where freed from limestone pebbles by the Hutchinson process, described on page 25, becomes a satisfactory material for manufacturing brick and drain tile.

(6). The Wisconsin drift, so far as developed by movement of ice from the north or northeast across eastern and central Minnesota, is

largely stony and coarse-textured and unsuitable for use. Very rarel there are silt or clay pockets in it..

(7). The lake silts laid down in bodies of water in the weste perior and Red River basins are locally thick enough to be used i industries, the plants at Wrenshall being a conspicuous instance. dinarily there is a thin deposit of lacustrine sediment in the deep of these old lake beds, but in certain localities it is replaced by while on the borders of the basins the bowlder clay and the gr beach ridges are prevalent surface features.

(8). In addition to the great glacial lakes of the Superior and River basins, there were numerous small lakes or ponded areas along border of the ice, in which silt was deposited. Such an area oc north of Princeton at the large plants of Brickton, and similar areas cur farther east along the northern edge of the lobe of ice that exte northeastward from the Mississippi to the St. Croix Valley above Twin Cities.

Since the retreat of the ice there has been only a slight modifica of the surface and very little accumulation of material or removal by e sion. A few lakes and swamps have been filled and a few have be drained. The large river channels have been silted up.

GEOLOGIC FORMATIONS AND ASSOCIATED CLAYS

ARCHEAN SYSTEM

The rocks belonging to the Archean system which are known in Minnesota consist of greenstones, granites, gneisses, schists, and jaspers. They underlie all other formations everywhere and constitute the basal member upon which the subsequent strata were laid down. In northern Minnesota these Archean rocks include the productive iron-bearing formation of the Vermilion Iron Range. In the western part of the State hornblende and biotite schists and granites are known to underlie the Cretaceous formations in many localities where they outcrop or have been encountered in deep wells. Granite and gneiss outcrop in central Minnesota and are known by well records to underlie the greater part of southern Minnesota.

In the southwestern portion of the State where the Archean rocks are covered by Cretaceous sediments, they are invariably decomposed near the top to a white clay. Evidence of this is clear in the numerous wells throughout the region, in addition to the occasional outcrops. The clay extends downwards in some instances to a depth of fifty feet, where it grades into soft rotten granite of various shades. The upper portion of the residual clay also grades into the Cretaceous sedimentary clays

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t the dividing line has rarely been determined. It is more than le that in some cases where great thicknesses of residual kaolin ɔorted, some Cretaceous clay is included. Much of the residual of excellent quality. Outcrops are known chiefly along the Min- Valley from New Ulm up to the vicinity of Montevideo. Well ; show this type of clay in Big Stone County at a depth of 250 to et; in Chippewa County at depths of about 700 feet; in Lac qui County at 150 feet; in Lyon County at 200 to 600 feet. Probably rs are extensive and more or less continuous in the counties north est where well records are not available.

: following analyses of the clay, and one of the clay after washing, ilable:

Table I. Analyses of Residual Clays.

	1	2	3	4	5
....	43.86	45.92	41.71	62.04	37.88
a	41.82	39.84	34.61	25.54	26.96
oxide			4.58	1.89	15.78
oxide			6.88		
ia	very small	very small	0.22		1.74
			1.16		trace
....	n. d.	n. d.	0.11		0.95
....	n. d.	n. d.	trace		
....	14.65	14.12	12.69		15.88
			101.96		

y from Morton. F. F. Grout, analyst. See U. S. Geol. Survey, Water Supply aper, No. 256, p. 310.
r washed from a decomposed granite, Redwood Falls. F. F. Grout, analyst. . S. Geol. Survey, Water Supply Paper, No. 256.
r from decomposed gneiss, Birch Cooley, near Morton. A. D. Meads, analyst. y partially analyzed by L. B. Pease.
hlunite." Average of three analyses by S. F. Peckham. Described in Minne- ota Geol. and Nat. Hist. Survey, Vol. 2, p. 196.

is hoped that this widespread residual clay may be used after a ng process as a kaolin for porcelain and china-ware products. A washing test in the laboratory on a few widely separated samples that about 50 per cent of the crude product can be washed through mesh sieve. This finer portion of the clay burns to a clear white and after being glazed shows very little darkening of the color. These re the most refractory in the State and are capable of being used highest grade of clay products. (See also Figs. 8 and 9.)

ALGONKIAN SYSTEM

s system is subdivided into the Keweenawan, Upper Huronian, ɔwer-Middle Huronian. Each of these groups is separated from er by a marked unconformity.

The lower-middle Huronian is not known to include clays, but consists of granites, granite porphyries, dolerites, slates, graywackes, and conglomerates. The sedimentary series attains a thickness of 5,000 feet in the northern part of the State.

Upper Huronian.—There are a number of distinct formations belonging to this series. These include the following: (1) Pokegama quartzite; (2) Biwabik and Gunflint iron formations; (3) Virginia slate and slates and schists near Carlton and Little Falls; and (4) acidic and basic intrusives. Besides these there is the Sioux quartzite, thought by some to be equivalent to the Pokegama, while others place it in the lower-middle Huronian.

Outcrops of these rocks are confined to the central and northeastern part of the State except those of the Sioux quartzite, which are in the southwest portion. The slates cover the largest area and attain great thickness. (See Plate II B.)

None of these rocks contains any clay deposits of importance, but experiments made in connection with this report show that some of the slates exposed in Carlton County, when crushed and mixed with a small amount of common clay from the drift, will make a beautiful fancy brick of high quality. In the Sioux quartzite are some layers of a silicified shale known as pipestone. No single body of it is over four feet thick, and it is of no importance in ceramic industries. Some ferruginous layers of clay in the Biwabik formation are called "paint rock." This paint rock does not melt at as low a temperature as might be expected from its iron content, and, where mining operations make it necessary to remove it it may be made use of for brick. Residual clays from mica schist outcrop along the Mississippi River in Morrison County, and, though they are not as refractory as those from the Archean, they fuse at a relatively high temperature.

The Keweenawan from the eastern and northeastern parts of the State is largely made up of basic igneous rocks with no clays. Some flows alternate with sediments, which are not, however, of a quality suitable for use as clay. At Two Harbors, on the north shore of Lake Superior, lenses only a few feet in length and a few inches thick were sampled to determine their character. Along Snake River just below Pine City a rather large bed of essentially the same material occurs. The clay does not slake or become plastic. It remains sandy and soft to a temperature of 2300° F.

Sediments, known as the "red clastic series," and probably of the same age as the Keweenawan igneous rocks, are known in the eastern and southeastern parts of the State and have been provisionally assigned to the Algonkian (?) system. These underlie sediments of Upper Cam-

brian age in the south, and are known only from well records. They are probably of the same age as the red sandstones and shales outcropping from Lake Superior southwest to Mora which lie unconformably over the Huronian and are locally called Hinckley sandstone. Shaley layers are especially abundant near the base of the formation. An analysis of this shale from near Fond du Lac is reported in the discussion of Carlton County.

CAMBRIAN SYSTEM

The Cambrian system embraces in order of age (the oldest being first), shales and white sandstones, underlying the Dresbach sandstone, the Franconia sandstone, the St. Lawrence formation, and the Jordan sandstone.

The lower formations, including the Dresbach and Franconia sandstones, are made up of 450 feet or more of fine-grained white sand with shaley beds and sandy shales and thin layers of limestone towards the base. The best exposures are to be seen along the St. Croix River north of Stillwater and at Dresbach on the Mississippi River just north of the Iowa line. Siliceous shales of variable character occur at these places, but are not likely to be of importance as clays.

St. Lawrence formation.—This consists of buff-colored dolomite interbedded with shale and sandstone. The shale is greenish in color and towards the top of the series there are several thin layers of green sand. The total thickness of the formation is about 225 feet. The best outcrops are found along the Mississippi and Root rivers, north of the Iowa line, although the St. Lawrence underlies practically all of southeastern Minnesota extending as far north as northern Washington County and westward to a point beyond Mankato, where it outcrops in the Minnesota River Valley. The shales are too thin to be important as brick material. They are so sandy that there is very little shrinkage up to the point of viscosity.

Jordan sandstone.—The Jordan sandstone consists of white to brown sandstone and has no clay. The thickness ranges from about 75 to 200 feet. It is confined chiefly to the southeast corner of the State, and it is well exposed in the Minnesota River Valley north of Mankato and in the bluffs along the Mississippi from Hastings to the Iowa line.

ORDOVICIAN SYSTEM

The Ordovician system in Minnesota is composed of the following members, the oldest being placed last:

6. Maquoketa shale
5. Galena limestone

4. Decorah shale
3. Platteville limestone
2. St. Peter sandstone
1. Prairie du Chien group (Shakopee dolomite and Oneota dolomite)

All of the Ordovician rocks are confined to the central and southern part of the State, where they rest conformably upon the Cambrian. Their attitude is almost horizontal, although they have a slight dip in general to the southeast.

Prairie du Chien group.—The Oneota dolomite is a buff to reddish dolomite which outcrops in numerous localities along the valleys and river bluffs in southern Minnesota. The texture of the rock varies from granular to crystalline, the latter variety being more typical. The thickness ranges from 75 to 200 feet. No clay is associated with the formation.

The Shakopee dolomite contains no clays, but consists of a maximum of 75 feet of yellow, buff, or red magnesian limestone which differs from the Oneota in texture and color and includes some sandy beds. It is finer grained and more granular. The Shakopee outcrops along the Mississippi and Minnesota river bluffs and in much of south central Minnesota forms the surface upon which the drift has been deposited.

The St. Peter sandstone consists in the main of a fine-grained, loosely consolidated white sandstone which often presents a yellow surface where it has been exposed to weathering. In thickness it ranges from 80 to 200 feet, the average being somewhat over 100 feet. In most parts of southern Minnesota the St. Peter is covered either by late Ordovician sediments or by the drift, or by both, but it outcrops along the Mississippi and its tributaries from Minneapolis south.

There is a 4-foot bed of shale above the sandstone of the St. Peter and below the main Platteville limestone, but it is too thin to be of value.

The Platteville limestone has an average thickness of 12 or 15 feet, although a maximum of 30 feet has been observed. The rock is a magnesian limestone, varying in texture from granular to thoroughly crystalline, and in color from buff to blue-gray. It outcrops over large areas in southern Minnesota from the Twin Cities southeast. It contains no clay of value.

The Decorah shale.—Lying on top of the Platteville limestone is a series of green shales with a maximum thickness of nearly 100 feet, though the average thickness is much less, probably 50 feet. Interbedded with these shales are numerous layers of hard granular limestone, some of which are composed almost entirely of fossils. In some

places these limestone layers constitute more than one-half of the total thickness of the formation. The limestone beds vary in thickness from an inch to several feet, but most of the layers are less than one foot thick. At the base is usually a thick shale about 10 feet, but above this the shale and limestone alternate in similar layers. The shale is fissile and crumbles easily. The extent of the shales is shown on the map (Plate I.) The line sketched is intended to show the limits of workable shale and not necessarily a definite horizon. Since the upper part of the shale grades into limestone, to the south,[1] a map of the horizon is of little economic importance. The northern and eastern limits are outcrops. On the west and south the Cretaceous and Devonian rocks overlap the Decorah and make it inaccessible. Even in the area mapped the glacial drift covers some of it so deeply that it may not be profitably worked. In the extreme southern part of the State the formation thins out to about 30 feet. From Cannon Falls as far as St. Paul the maximum thickness is observed. North of St. Paul the formation is eroded away. Throughout the southern part of the State its elevation above sea level ranges from 1,000 to 1,300 feet, on account of very gentle folding. It is flat-lying wherever noted. The Decorah is one of the most important clay formations in Minnesota. The shales, when crushed and pulverized and mixed with water, yield a greenish plastic clay which is used extensively near St. Paul and in Goodhue County for the manufacture of pressed brick, fancy brick, hollow ware, drain tile, and common brick. The St. Paul plant is most favorably situated with respect to market, but, besides the plants already operating, there might be room for developments at Faribault, Rochester, and Cannon Falls. The high grade of the product eliminates most of the competition of common brick. In general, the shale burns red, but can be turned green and brown and mottled by reduction during firing. It needs a much lower temperature for vitrification than most clays—about 1800° F.—but has a good range, so that it can be well vitrified without loss. The material and process have not been manipulated to produce a paving brick, though this may yet be possible. The upper layers differ slightly in color and behavior from the lower ones. Stiff-mud machines and presses are most successfully used in working the shale. Figs. 8 and 9 show the behavior during vitrification.

The shale rarely outcrops, and the stratigraphic method of prospecting should be applied. The top of the shale is likely to be a persistent spring horizon, and grass usually covers the slope. The topographic relation of the shale and limestone is shown in Fig. 4. Analyses are re-

[1]Sardeson, F. W., Galena series: Bull. Geol. Soc. America, Vol. 18, pp. 179-94.

ported in Table VI, in the discussion of Dakota County. Tests made by the Engineering Department of the University of Minnesota show that bricks made from the Decorah shale are of excellent quality. Soft red brick, not burned to vitrification, have a strength of 1,500 pounds per square inch; partly vitrified bricks with a rather high porosity still evident, have a strength of over 3,100 pounds per square inch.

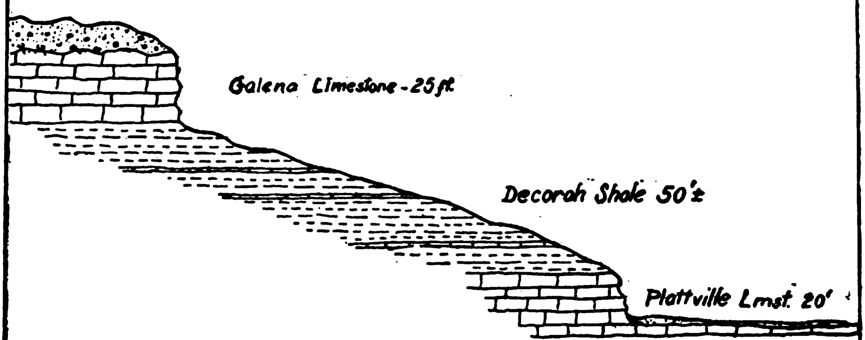


Figure 4. Scale 1" = 50'
Profile showing topographic features of Decorah shale outcrop Olmsted County

The Galena limestone overlies the Decorah, or in part grades into it. It consists of granular or massive limestone and caps the hills in the southeastern part of the State. Exposures are few on account of the loess and drift covering. In typical outcrops there are only a few thin shale beds of no value. A sample was taken southwest of the town of Chatfield, Fillmore County. The layers are but a few inches thick and could hardly be obtained free from limestone. Fragments of the dry shale slake in three minutes to a mass of small lumps. Its plasticity is fairly high. It requires 22 per cent of water for molding. Its air shrinkage is 5 per cent. At low temperatures the burning resulted in a salmon-colored product without any fire shrinkage, and with an absorption of about 28 per cent. It becomes buff and hard at cone 4 (2210° F.) and turns gray at cone 6 (2282° F.), but is still undeformed at even higher temperatures, though wholly melted at cone 12.

The Maquoketa shale is in Minnesota an alteration of dolomitic shale and limestone with shales too thin to be of value. Outcrops are known only in Fillmore County where the formation has a maximum thickness of 80 feet. The dry clay slakes in 10 minutes. Its plasticity is fairly high and it requires only 15 per cent of water for molding. Its tensile strength is about 100 pounds per square inch and its air shrinkage

less than 3 per cent. It could safely be dried with artificial heat. In burning up to a temperature of cone 2, several samples were buff in color without any fire shrinkage and with an absorption of 27 per cent. It does not become hard at cone 3 (2174° F.), but it has become viscous at cone 6 (2282° F.). It is, therefore, impracticable to burn this clay to a hardness approaching vitrification. This is the only sample of Maquoketa shale available.

DEVONIAN SYSTEM

The Devonian rocks in Minnesota consist of sandstone and limestone and shales, the total thickness of which is not more than 100 feet. They are confined to the extreme southern part of the State where they constitute extensions of the Devonian formations more general in Iowa. In the vicinity of Austin, marly layers of the Devonian have been used to mix with the plastic clay which overlies them. The lime in the added marl improves the working quality and gives a product with lighter color.

Where Bear Creek crosses the line between Fillmore and Mower counties, shale beds were found to be as much as one foot thick and there is every indication that they extend over considerable territory. They are yellow to buff in color, very sandy and lean, and, of course, could not be separated commercially from the interbedded limestone. The shales slake in about four minutes and develop a surprising amount of plasticity considering their sandy appearance. They require about 20 per cent of water for molding. Their tensile strength is nearly 100 pounds per square inch. They can be dried rapidly without danger and retain their tensile strength even after being separated as by an auger and pressed together. The air shrinkage is about 3 per cent. At very low temperatures the burning tests yield a salmon-colored product, but at the higher temperatures buff colors prevail.

Cone. No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Buff	......	27
2	Buff	1	23
5	Buff	......	......

The clay becomes hard at cone 03 (2000° F.) and viscous at cone 6 (2282° F.).

CRETACEOUS SYSTEM

Wherever the Cretaceous rocks are found in Minnesota, they consist of soft sandstones, shales, and clays, and, locally, have thin beds of conglomerates at the base. They cover most of the western part of the State,

below the drift, and numerous scattered areas occur throughout the southern, central, and northern portions. Outcrops are few on account of the drift cover, but numerous well records have helped to determine the general distribution. The maximum thickness is about 500 feet in this State. The upper portion is composed chiefly of soft blue or gray shales and clay, while deeper down white sandstone and kaolins are encountered. In the northern part of Minnesota there are a few occurrences of Cretaceous conglomerate at the base of the shale overlying beds of iron ore. The pebbles in the conglomerate are composed of hard hematite. In the western part of the State the Cretaceous rests upon the decomposed Archean granites and gneisses. There the base of the shale is white clay with conglomeritic or concretionary texture and contains quartz pebbles. In a few places where the Cretaceous lies in contact with Paleozoic sediments the conglomerate is not prominent, but the clays are similar to those just mentioned. The variation of the conglomerate with the bed rock is an indication that the white clay has been transported only a short distance.

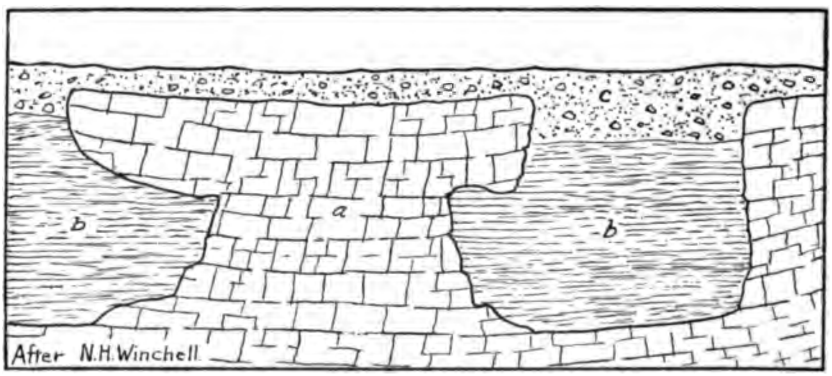


FIGURE 5. SECTION SHOWING THE OCCURRENCE OF CRETACEOUS CLAY NEAR MANKATO
a. SHAKOPEE DOLOMITE. *b*. CRETACEOUS CLAY. *c*. DRIFT.

The Cretaceous beds contain the highest grade clays to be found within the State. Some of them are used for stoneware, pottery, sewer pipe, and fire brick. At present there are but few areas of Cretaceous clays known where a good body of material lies close enough to the surface to be profitably excavated, but it is very probable that more detailed prospecting in the drift in the vicinity of Cretaceous areas would result in the discovery of new deposits of valuable clay. For convenience in discussion of the clay deposits the basal part of the formation where pebbly or concretionary will be treated separately, and it will be

A. BASAL CRETACEOUS CONGLOMERATE, NATURAL SIZE.

B. CRETACEOUS CLAY IN THE PIT AT CLAY BANK, GOODHUE COUNTY.

necessary to refer often to the Archean residual clays which cannot everywhere be sharply distinguished. The higher formations have the common characteristics of marine or lacustrine sediments.

The basal Cretaceous clays.—These are most prominently exposed along the Minnesota River in the bluffs on both sides of the valley from Granite Falls to New Ulm and probably extend to Mankato. (See Figs. 5 and 6.) Under the drift white clays of apparently similar character are found through several counties on either side of this strip along the river. The great extent under the drift is further confirmed, and the certainty that these deposits are not entirely Archean residuals is shown by occurrences near Richmond in Stearns County, and near Bowlus in Morrison County. There is a general variation in the character of these basal Cretaceous clays as traced through these outcrops and farther north. Where

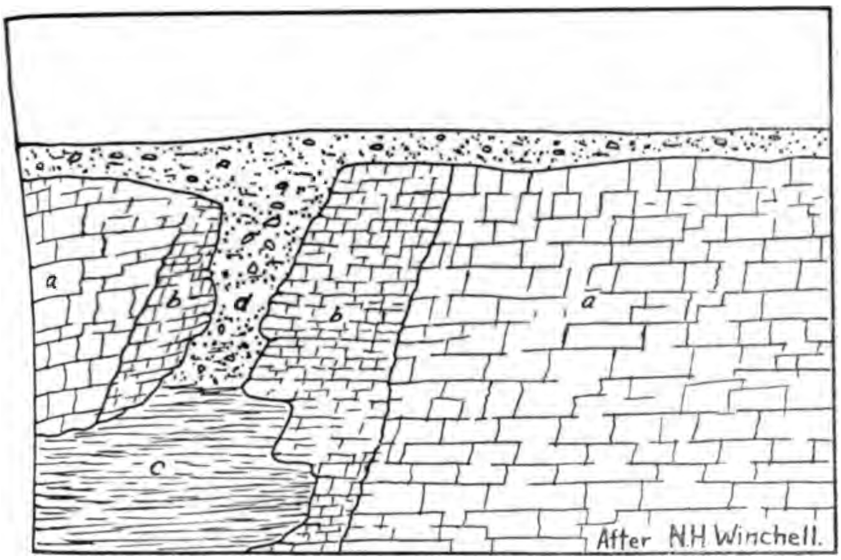


FIGURE 6. SECTION NEAR THE RAILROAD BRIDGE, MANKATO.
a. SHAKOPEE DOLOMITE. *b.* WEATHERED LIMESTONE.
c. CRETACEOUS CLAY. *d.* DRIFT.

Archean or other bed rock formations are feldspathic in character, the basal conglomerate consists largely of clay. On the iron ranges, immediately overlying the Huronian iron ore deposits the Cretaceous basal conglomerate is good iron ore. At Bowlus the basal Cretaceous has the appearance of an iron-stained clay and analysis has shown it to be high in iron. This gradation in widely separated outcrops may be taken as some slight indication of the continuity and contemporaneous formation

of the various materials. The clays which outcrop in the Minnesota Valley, however, are peculiar in their texture and contain numerous beds or layers, varying from one foot to many feet in thickness, which appear to be concretionary and have the appearance of bauxite. The rounded spots show very little concentric structure, are at some places more highly colored than the matrix, and at others less highly colored. (See Plate III, A.) In a few very instructive outcrops these rounded spots, which appear to have the same composition as the matrix, were associated with rounded pebbles which proved to be quartz. It is therefore concluded that not all of them are concretionary in their origin. It is possible that part of them are concretionary and part are water-worn fragments. Possibly the original pebbles were quartz and feldspar, the latter having been subsequently altered, as the bed rock below has been altered. Analyses of several samples with intent to show the content of bauxite resulted negatively. In the sample from Bowlus (see Morrison County) there was certainly too much alumina for the mineral kaolinite, so that there is some probability that concretionary bauxite originated during or after the formation of the basal Cretaceous conglomerates. The later Cretaceous shales overlie these beds with a very abrupt change in lithologic character.

Summarizing the properties of the basal Cretaceous clays, we may say that they are usually highly refractory, fine-grained, and rather siliceous, and sometimes heavily stained with iron. Their plasticity is medium and their tensile strength is rather low. The shrinkage both in drying and burning is very small. They burn hard at temperatures ranging from cone 06 to cone 35. It seems very likely that the whiter samples could be washed to produce a kaolin fit for china ware. Analyses are reported in the discussions of Morrison and Redwood counties. (See Figs. 8 and 9.)

The Upper Cretaceous shales.—These shales are supposed to underlie much of the western part of the State, but are heavily covered with drift over most of the area. The eastern border cannot be accurately mapped on account of the drift cover. Beyond it there are many outliers and patches which have been transported by ice.[1] (See Plate III, B.) Some of the most valuable deposits in the State are of this age. In places the shales are interbedded with sandstone and, less often, with limestone. Nearly all of the shales are gray in color, but some have a greenish tint. They are exceedingly plastic with a peculiar waxy feel, owing apparently to the presence of some mica scales in the clay. The clay beds overlie the basal conglomerate with an abrupt change in

[1] Sardeson, F. W., So-called Cretaceous of southeastern Minnesota. Jour. Geol. Vol. 6, p. 679.

color. Many of them are contaminated with organic matter, and many are somewhat ferruginous. The thickness of any occurrence of this shale depends largely upon the amount of subsequent erosion which has occurred. Outcrops ranging from 1 to 50 feet in vertical banks have been seen. Well records reveal a much greater thickness under the drift. A peculiar occurrence is shown in Figs. 5 and 6. In the southern and southeastern parts of the State they are known to be semi-refractory, but the western and perhaps the northern deposits are more uniformly ferruginous and not of so great value. Nearly all of the Cretaceous shales have a good range of vitrification and can be burned hard without danger of fusion.

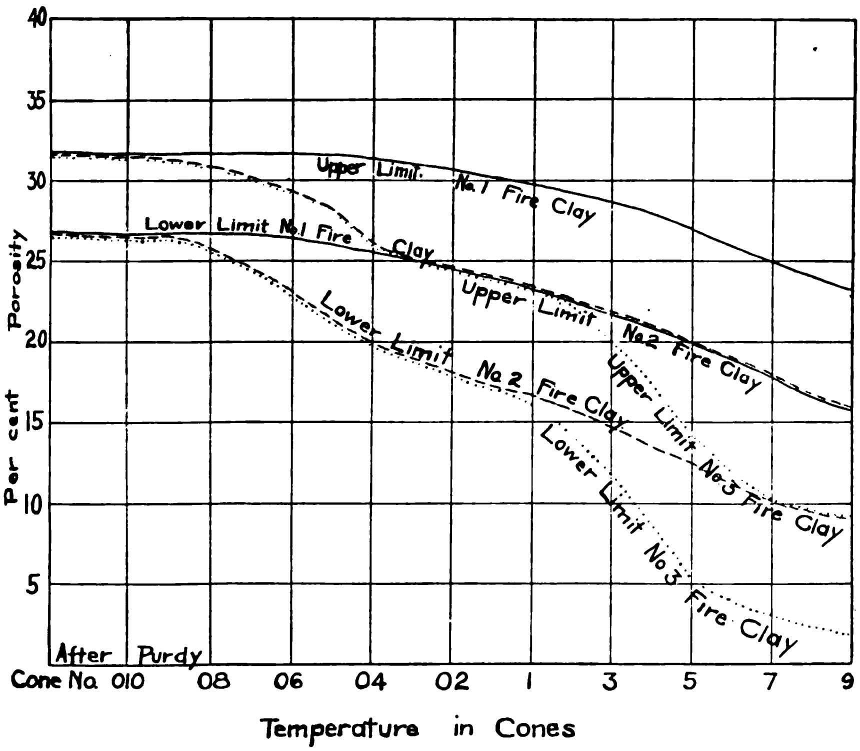


FIGURE 8. CURVES SHOWING THE LIMITS OF POROSITY OF FIRE CLAYS AT VARIOUS TEMPERATURES.

Summarizing the properties of the Cretaceous shales, we may give the following averages. The water required for molding is 27 per cent. The air shrinkage is less than 7 per cent. The plasticity is satisfactory and the tensile strength is high enough for the production of any of the complex forms constructed in the most elaborate of the factories in this

State. Upon burning, many of the clays become dense and hard b 2000° F. The shrinkage on burning to thorough vitrification is about 4 per cent. The absorption is rarely as high as 10 per cent ; the clay becomes hard. Several of the clays, though burning very d give indications of withstanding high temperatures without losing strength. See Figs. 8 and 9 for the behavior during vitrification.

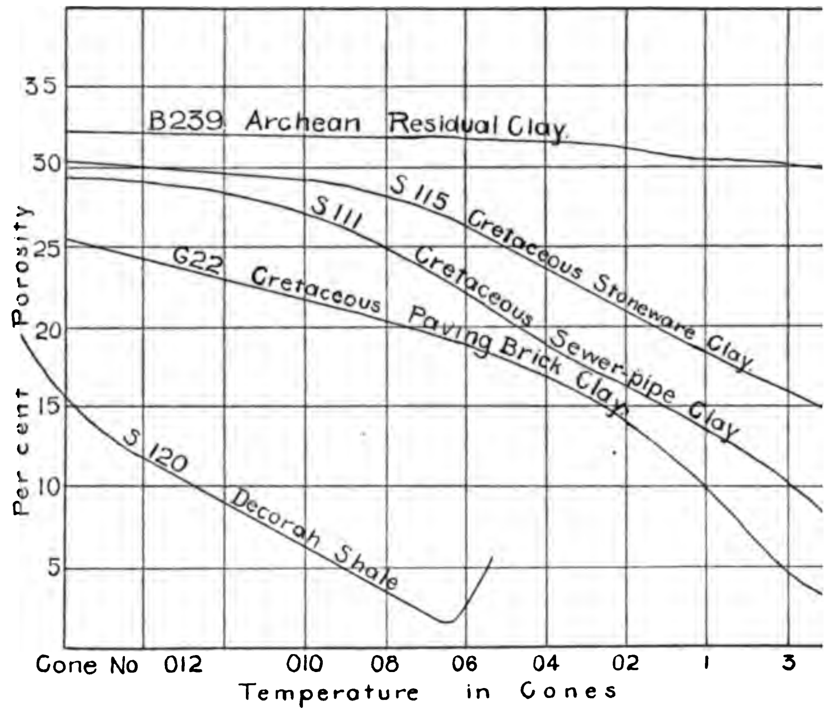


FIGURE 9. CURVES SHOWING THE POROSITY OF RESIDUAL CLAYS AND PRE-PLEIST SHALES OF MINNESOTA, AT VARIOUS TEMPERATURES.

The plants making use of these shales are mentioned in the re on Goodhue and Brown counties. In Plate I, the locations of some p are shown. The quality of the material used at Red Wing is know the reputation of the stoneware and sewer pipe. They are both e lent. Bricks are made from Cretaceous shale both by soft-mud and mud methods. Soft-mud solid red brick show a strength of 3,600 po per square inch. Stiff-mud hollow brick, made light in weight for ping, show compressive strengths from 900 to 1,600 pounds per sq inch, depending on how well they are vitrified. The modulus of ru is from 500 to 1,500 pounds per square inch.

The following analyses of the shales are available:

Table II. Analyses of Cretaceous Shales

	1	2	3	4	5
Silica	69.84	61.32	68.298	69.050	58.14
Alumina	23.07	12.27	18.266	18.830	19.40
Ferric oxide	0.48	3.62	2.867	2.607	5.52
Ferrous oxide	....	4.18	....	....	......
Lime	0.11	.99	.719	.296	0.79
Magnesia	0.14	1.76	.802	.622	1.52
Sodium	trace	.42	.81	1.066	.54
Potassium		3.59	.60	1.461	2.09
Barium oxide	....	.05	....	....	......
Manganese oxide	....	.27	....	....	......
Phosphorus	....	.27	....	....	......
Sulphur	....	.19	....	....	......
Titanium	....	.66	....	....	.68
Moisture	6.35	....	1.29	.898	2.10
Ignition	....	10.73	6.155	4.912	8.81
	99.99	100.32	99.908	99.74	99.59

1. Red Wing, Goodhue County. Analyses reported by J. H. Rich to H. Ries.
2. New Ulm. Brick clay, U. S. Geol. Survey Bull. No. 60, p. 151. T. M. Chatard. A brick made from this clay is reddish brown, strongly sintered, somewhat fractured. Hon. John Lind took the sample in south bank of Cottonwood River on section line where river crosses, east of wagon road crossing, south of New Ulm.
3. Red Wing clay. C. P. Berkey, analyst. Sample from Minnesota Stoneware Co., Red Wing, April 22, 1902.
4. Red Wing stoneware clay, air dried. C. P. Berkey, analyst.
5. Dakota sample. Clay sampled by A. Parker, Brown Valley, just beyond the state line. F. F. Grout, analyst.

Table III. Analyses of Cretaceous Shales

	6	7	8	9	10	11
Silica	59.72	70.10	87.70	93.65	73.34	68.70
Alumina	30.00	16.99	7.24	2.15	14.75	18.04
Iron oxides	....	trace	trace	0.25	5.45	1.53
Lime	0.82	....	0.67	0.20	0.28	1.24
Magnesia	0.51	....	0.07	0.12	0.05	0.56
Soda	....	....	3.17	trace	trace	0.24
Potash	....	10.69	0.49	trace	trace	5.28
Phosphorus oxide	....	....	....	....	....	0.09
Sulphur trioxide	....	0.23	....	....	....	......
Titania	....	....	....	....	....	......
Moisture						
Ignition	10.34	1.98	trace	2.25	4.71	1.40
Organic matter	....	....	trace	....	....	trace
	101.39	99.99	99.34	98.62	....	......

6. Ottawa, Ottawa Brick Co. H. Ries.

7, 8, 9, 10, and 11, from Final Rep. Geol. & Nat. Hist. Survey, Vol. 1, p. 438.

7. Near Mankato, clay filling hollows in Shakopee dolomite.
8. Near Mankato, Sec. 20, from "white clayey bed of considerable extent."
9. Near Mankato, Sec. 36. "Nearly white, very fine grained, somewhat friable earth."
10. Same locality, red ochery clay.
11. Near Mankato, clay or shale between Shakopee dolomite and Jordan sandstone in L'Hullier Mound.

TERTIARY SYSTEM

Rocks of Tertiary age have not been identified with certainty in Minnesota, but there are probably thin stream deposits of this age at various

places in the State. These Tertiary stream deposits cannot be differentiated from the more recent surficial deposits and most of them have been worked over by more recent streams, or by the ice, and mixed with the material of the drift.

QUATERNARY SYSTEM

Pleistocene deposits

Following the outline of Pleistocene history, as given above by Professor Leverett, we may divide the deposits into the following groups: (1) Nebraskan drift (no clay); (2) Aftonian (only thin clays); (3) Kansan and Wisconsin drift from the northwest—the gray drift; (4) Wisconsin drift from the north and northeast—the red drift; (5) lake clays of laminated structure,—first, those of gray color, or yellow if weathered, and, later, those of red color; (6) the loess. These divisions are based on differences in character, though one division, such as the gray drift, may include material of two or three separate invasions. Furthermore, the red drift from the north is of somewhat different material than that from the northeast, but the associated clays are so much alike that no distinction is made.

AFTONIAN SOIL

Following one of the early drift invasions, vegetation apparently spread over the southern part of Minnesota, and a soil was formed which subsequently was buried under the recent deposits of dray drift. The soil as now found is dark gray in color, and varies from 1 to 4 feet thick. It can easily be traced for perhaps 20 rods along the Rock Island Railroad within 2 miles southeast of Faribault. Two analyses, made in 1906 by F. F. Grout for Professor Leverett, of the United States Geological Survey, are available.

Silica	65.10	55.10
Alumina	10.42	10.60
Iron oxides	4.74	4.47
Magnesia	2.06	2.06
Lime	4.52	7.26
Moisture	1.05	1.58
Ignition	8.10	15.32
Titanium oxide	0.82	0.60
Alkalies, etc., by difference	3.19	3.01

THE GRAY DRIFT CLAYS

Glacial drift with a high proportion of clay and generally, but not

always, a gray color and a superficial alteration to yellow, covers over half of the State, having come in from the northwest with lobes which reached in a few places completely across to the eastern border of the State. Reference to the map, Plate I, will show its general distribution. Though the gray drift may be the product of more than one invasion, the clays were derived from the same regions and are of the same type. The older Kansan and pre-Kansan drifts may be more weathered and leached, but no distinction is made in this discussion. The clays are characterized throughout by the occurrence of limestone pebbles, which render them unfit for the production of clay products, unless some process is applied for their removal. This has been done successfully in Minnesota at Hutchinson, where a unique process has developed for washing the gravel out. This is fully described under Technology. Besides the washing process, there is a screening process, and a fine grinding process, either of which may in some cases render gray drift available for making brick.

The drift is usually a surface formation and has no overburden except a few inches of soil. Loess may have accumulated over much of it, but has either been washed away, or mixed with slope wash so as to be pebbly and much like the original drift in nature.

In summarizing the properties of the clay found in the gray drift, we may report the following averages. Twenty-three per cent of water is required for molding. The tensile strength is nearly 100 pounds per square inch, and the material can be rapidly dried without serious injury. The air shrinkage is 5 per cent. The fire shrinkage is only 2 per cent at the time the clay becomes hard, and about 5 per cent just before it becomes viscous. The absorption meanwhile ranges from about 19 per cent down to 6 per cent. The average clay becomes hard at cone 02 (2030° F.), and viscous a little above cone 3 (2180° F.). The range of vitrification is therefore less than 200° and it is usually unsafe to burn the clays very hard. See also Figs. 10 and 11. The stiff-mud process is usually successful. By cleansing the clay of its limestone, the properties can be greatly improved, and the washing or "slumming" process used at Hutchinson and the dry cleansing process used at Jackson are recommended for careful investigation by all who plan to organize any ceramic industry making use of the gray drift. Exceptional locations may be found where a simple grinding process will be satisfactory, but the washing process is much more certain and applies to a much wider range of material. Analyses of washed material are reported in the discussion of McLeod County. As the northern part of the State becomes more settled and as the farmers in various parts of the State find it desirable to install systems of tile drainage, the local demands for a good quality of tile such as can be produced from this gray drift will increase and be so permanent as to warrant the

erection of several plants of medium capacity. Such a plant might well make use of about half a dozen down-draft kilns, and nearly every situation in the western half of the State where the demand is at all favorable, will undoubtedly be found supplied with gray drift of the proper quality. The radius through which such a plant would find its market would probably rarely be over 50 miles, but within Minnesota several such plants may well be established. Brick made from washed gray drift are usually salmon-colored and some are buff. The crushing strength, as tested at the Engineering Laboratory of the University, was over 2,400 pounds per square inch. The drain tile made from washed gray drift seem to be exceptionally good in the matter of resisting frost.

GLACIAL LAKE AND RIVER CLAYS: GRAY LAMINATED CLAYS

In many parts of the State and chiefly along the valley of the Minnesota and Mississippi rivers and their tributaries, there are beds of clay which show a very interesting kind of stratification in distinct, nearly horizontal, layers, varying from a fraction of an inch to 8 inches in thickness. These layers are dark blue-gray where fresh, and yellow where they have been exposed to oxidation. (See Fig. 2.) They are often finely laminated with alternating fine sand and rich partings of clay. Plate I shows the location of large deposits and Plate IV shows a typical exposure. There is a tendency to split along the darker partings which are seen to extend continuously without grading into one another. The bedding is nearly level, but may dip a few degrees on either side or even be locally folded into arches or basins. (See Plate V, B.) In some clear exposures there are as many as 60 layers, all nearly alike, in a depth of 15 feet. The alternating conditions which produced them were evidently repeated 60 times without interruption. A probable explanation is that these divisions mark so many years occupied by the deposition of the clay. Along the flood plain of a river, clay would settle only where hollows were formed by inequalities of surface outside the path of the main current. The structure of this clay and its occurrence only in glaciated regions or valleys draining from glacial drift, indicate that the formation was accumulated by streams coming from a melting ice sheet. If this suggestion is correct,[1] it is apparent that the floods would be greater and bring a coarser sediment in summer than in winter, and thus produce the alternating layers found. Such clays have long been known and used along the Minnesota River at Chaska and Jordan, and along the Mississippi River from Minneapolis to Brainerd. (See Fig. 7.) They are calcareous and suitable mainly

[1] Winchell, N. H., Final Rep. Minnesota Geol. and Nat. Hist. Survey, Vol. 1, 1884. p. 467, and Vol. 2, 1888, p. 132.

LAMINATED CLAY, WRENSHALL.

for brick and fire-proofing. The present investigation shows a much wider distribution than has heretofore been reported, and there is every reason to expect that still other deposits will be developed. The leached, upper yellow clay is much more satisfactory than the lower gray clay. The latter cracks badly on drying and the preheating mentioned in Chapter II is recommended.

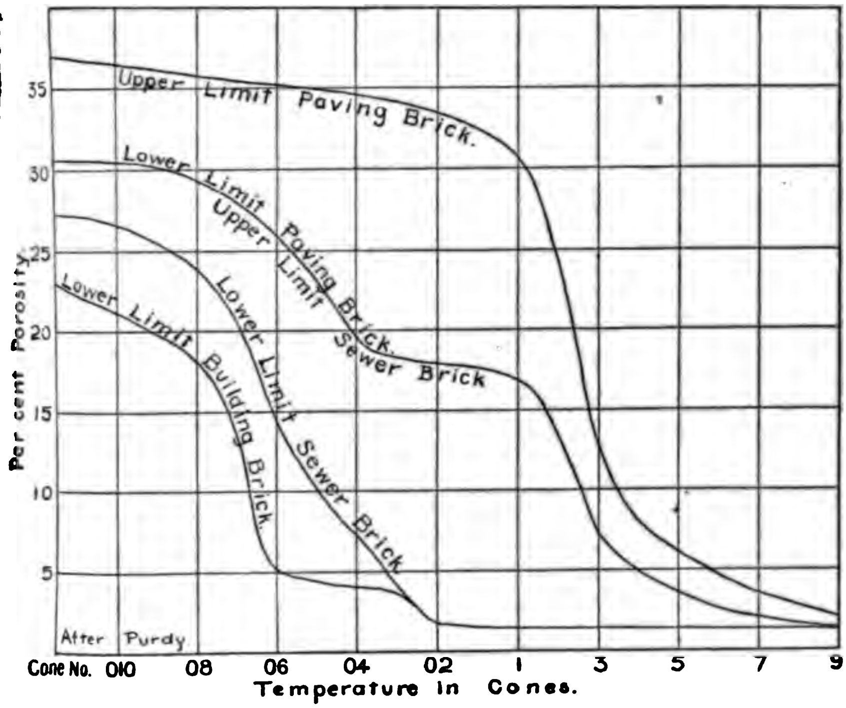


FIGURE 10. CURVES SHOWING THE LIMITS OF POROSITY OF BRICK CLAYS AT VARIOUS TEMPERATURES.

Summarizing the properties of the gray laminated clays, we have the following averages. The clays are rather highly plastic, and require 29 per cent of water for molding. The tensile strength is about 100 pounds per square inch, and is not seriously affected by rapid drying. The air shrinkage is nearly 6 per cent, but this average figure is increased by the presence in the data of some figures for the unused, underlying blue clays. When burned hard, the fire shrinkage is only a little over 2 per cent. The maximum shrinkage observed before the clay reached viscosity will average about 8 per cent. The absorption at the temperature at which the clay becomes hard is about 23 per cent, and this drops to 10 per cent before the product is in danger of being melted. The

average clay burns hard at cone 02 (2030° F.), and becomes visc at cone 3 (2174° F.). These figures show a rapid fusion, and the (should not be used in attempts to make vitrified products. (See F 10 and 11.) It is suitable for common brick and hollow ware, : for fire-proofing of excellent quality, and the product will usually cream-colored. The quality of the products is mentioned in the cou descriptions of Anoka, Carlton, Carver, and Millelacs counties.

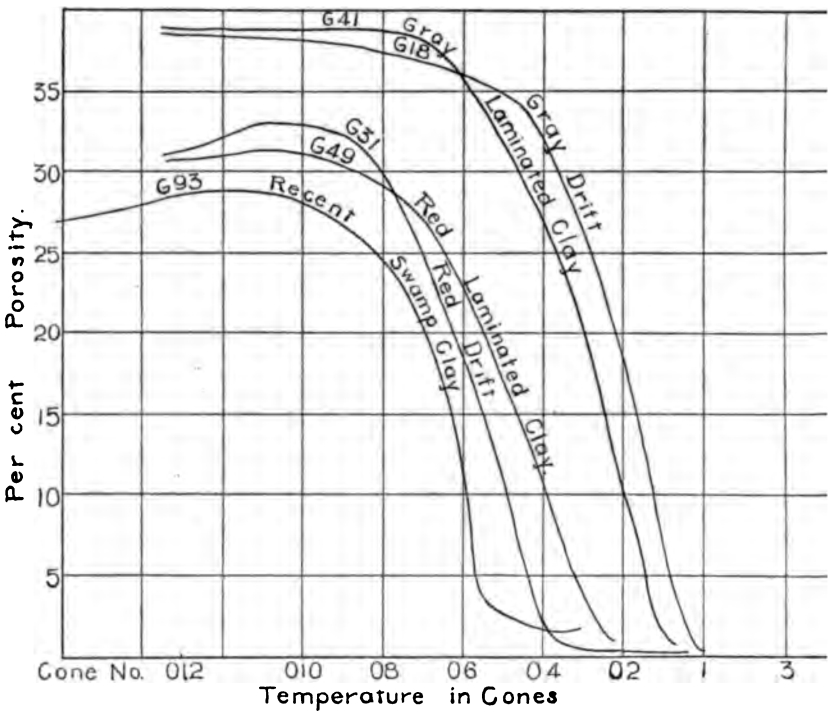


FIGURE II. CURVES SHOWING THE POROSITY OF PLEISTOCENE AND RECENT CLAY MINNESOTA AT VARIOUS TEMPERATURES.

THE RED DRIFT CLAYS

The general distribution of the red drift is along the eastern bo of the State (see Plate I), from Dakota County on the south to I County at the north. It is most prominent in the counties which touch border, and, where found west of these counties, it is frequently ove by a thin layer of gray drift. (See Plate V, A.) However, a lobe of red drift without such a covering of gray drift extends over to the I sissippi River in Morrison County.

Summarizing the properties of the red drift, we find its plasticity quite as great as that of the gray drift, but still perfectly satisfact

The materials tested have been of two types; first, the extremely pebbly and apparently unmodified drift and, second, the material accumulated at the front of the glacier as outwash—sandy rather than pebbly. These two types require slightly different treatment, but have been considered together for the following averages. (See Plate II, A.) Water required for molding is 23 per cent. The tensile strength is over 100 pounds per square inch, and is only a little lower if the clay is subjected to rapid drying. Shrinkage on drying is 5 per cent, and the fire shrinkage ranges from 2 per cent at the time the clay becomes hard to 6½ per cent by the time the clay is fully vitrified. The absorption is only 15 per cent when the clay is burned hard. The average clay begins to vitrify at cone 04 (1958° F.), and reaches viscosity at cone 3 (2174° F). It has thus a range of over 200° and can safely be burned to a vitrified brick, as is already done at Coon Creek. (See Figs. 10 and 11.) The excellence of the products of the red drift is shown by tests made by the Experimental Engineering Department of the University, on a few well-burned brick. The crushing strength was over 7,000 pounds per square inch.

GLACIAL LAKE AND RIVER CLAYS: RED LAMINATED CLAYS

Along the eastern border of the State (see Plate I), and extending a considerable distance into Wisconsin, are a series of deposits of laminated clay which have a striking red color, although in texture and relationships they seem to be similar to the gray laminated clays previously described. There can be very little doubt that their origin was dependent upon the same seasonal alternation of deposits of sand and clay brought by water from the melting ice sheet.[1]

Summarizing the properties of the glacial lake and river clays of red color, we have the following averages. Twenty-three per cent of water is required to develop the plasticity, which is only medium. The tensile strength is less than 100 pounds per square inch, but the material can safely be dried with artificial heat. The air shrinkage is 5 per cent. The clays become hard at cone 04 (1958° F.), and reach viscosity at cone 2 (2138° F.). At the temperature at which they become hard, fire shrinkage is 2 per cent, and the absorption, 16 per cent. Before the clays reach viscosity, the fire shrinkage may increase to 8 per cent. (See Figs. 10 and 11.) It is greatly to be hoped that these red burning clays may be developed to such an extent as at least partially to destroy the need of importing this type of material from Wisconsin as is now done. The extensive brick works at Menomonie, from which the Twin Cities and other parts of the State receive large quantities of red brick, make use of

[1]Berkey, C. P., Laminated clays of Grantsburg, Wis.: Jour. Geology, Vol. 13, p. 35.

laminated red clays of appearance and character similar to those found in eastern Minnesota. Another use that should be made of these clays is as a slip or glaze for semi-refractory stoneware. The red clay of the western end of Lake Superior was utilized for a short time in the town of Superior, Wisconsin, though it would seem from the bricks now to be seen in the old buildings in Superior that the clay was not burned at a sufficiently high temperature. For an analysis, see the report on Cook County. H. Ries[1] gives the following analysis of this type of red clay which appears to extend into Minnesota without change of character.

Silica	54.36
Alumina	13.40
Iron oxide	7.97
Lime	3.50
Magnesia	1.23
Potash	2.16
Soda	1.53
Titanic acid	.07
Loss on ignition	16.17
	100.39

The following analyses, most of them of Minnesota material, give evidence of the general character of the laminated clays.

Table IV. "Tripoli"

	1	2	3	4	5	6	7
Silica	77.7	77.00	82.50	70.00	77.00	77.00	77.50
Alumina	3.4	1.50	7.50	9.00	8.50	9.00	9.00
Iron oxides	3.5	7.00	....	....	....	....	....
Lime (with trace of Mg.)[1]	8.2	12.00	7.75	10.75	12.00	11.50	10.75
Water, etc.	7.2	2.50	2.25	2.75	2.50	2.50	2.75
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1]In analyses 2-7 inclusive, lime and magnesia (trace) were determined by difference. All are quoted from Winchell, N. H., Final Rep. Geol. and Nat. Hist. Survey, Vol. 2, p. 394 et seq.

1. Tripoli, Stillwater. J. R. Eckfeldt, analyst, U. S. Mint, Phila.
2. Tripoli, Stillwater. Upper stratum of lower bed.
3. Tripoli, Stillwater. Small shaft at lower bed.
4. Tripoli, Stillwater. Dark seam through lower bed.
5. Tripoli, Stillwater. From middle of 20-foot exposure.
6. Tripoli, Stillwater. From water-line of 20-foot exposure.
7. Tripoli, Stillwater. From upper exposure on the creek.

[1]Ries, Heinrich, The clays of Wisconsin: Wisconsin Survey, Bull. No. 15, p. 168.

Table V. Red laminated clays

	1	2	3
Silica	57.79	58.52	64.76
Alumina	12.63	14.98	15.45
Iron oxide	8.88	7.92	4.86
Titanium	0.82	....	....
Magnesia	4.11	3.39	4.02
Lime	3.33	5.26	4.22
Soda	1.75	....	....
Potash	2.71	....	....
Loss on ignition	2.50	7.92	5.96
Moisture	6.10	....	....
	100.62	97.96	99.17

1. Pine County. Red laminated clay. F. F. Grout, analyst.
2. Grantsburg, Wis. Laminated clay. Mixture of layers, worked. Fairly representative. Berkey, C. P., Jour. Geology, Vol. 18, p. 38.
3. Grantsburg, Wis. From uppermost layers. Do.

LOESS

The loess is usually considered a wind-blown deposit, formed chiefly from glacial material after the ice had receded and before vegetation regained a foothold. In this State the most important deposits occur in the southeastern counties in the so-called "driftless area," as shown on Plate I. Over the uplands the loess varies from 2 to 4 feet in thickness, but in the valleys and especially on the terraces along the sides of the valleys a much greater thickness occurs. Its origin appears to be similar to that of sand dunes, but the loess is the material which, being finer grained, is carried farther than the sand. At a great many of the smaller brick plants in the State, the main deposit of clay is overlaid with loess clay and the two have been washed down the slopes together. Where the two are exposed together, they may be mixed for the manufacture of brick.

Summarizing the properties of the loess clay, we may say that they are quite uniformly as follows. The plasticity is only medium, and the water required for molding is 24 per cent. The tensile strength is not very high. The air shrinkage is 4 per cent. The fire shrinkage during vitrification increases from 2 to 7 per cent, while the absorption decreases from 21 to 6 per cent. The range of vitrification is about 200° F., from cone 02 to cone 4. An analysis is reported in the discussion of Steele County.

Tests were made on loess clay bricks by the Engineering Department of the University. The strengths were not uniform and apparently were greater in wet bricks than in dry ones. The minimum strength is 1,300 and the maximum 3,800 pounds per square inch. The average absorption is 15.6 per cent and the modulus of rupture is 582 pounds per square inch.

CLAYS OF THE RED RIVER VALLEY

The retreat of glacial ice towards the north probably occupied thousands of years, and when the ice had vacated large natural depressions like the Lake Superior basin and the valley of the Red River of the North, the ice dams across the northern sides of the basin caused the accumulation of immense lakes. The one which occupied the valley of the Red River is known as Lake Agassiz, and can be studied by its beach ridges and to some extent by the delta deposits formed by the incoming streams. But the deposits of Lake Agassiz do not seem to be as largely made up of clay as those formed in the Lake Superior basin. The drift on each side of Lake Agassiz has a moderately rolling surface. Within the area covered by the lake, the contour is much smoother and more even, but the drift shows only slight traces of stratification. Nearer the shore lines the wave action piled up beach ridges of sand and gravel, at the same time washing away the finer grained material to be deposited as clay farther from shore. But these clay sediments were evidently of small amount, and are hardly noticeable over most of the area. Very thick beds of stratified clay, however, occur in the central portion of the Red River Valley, and their position shows that they were not deposited by the waters of the lake, which must have spread much more widely over its entire area. At the present time much of the area of the stratified clay is covered by the higher flood of the Red River, and probably no portion of these stratified clays is more than 10 feet above the high water line of the Red River or its tributaries. Since the river may have been much larger about the close of the glacial epoch, it seems clear that the clays were deposited as alluvium, in part of glacial time, and in part recent. They are therefore given a separate heading, and they are prominent enough to deserve separate discussion. Their depth and the width they cover increase northward. At McCauleyville, the deposit is about 2 miles wide and about 50 feet in depth, while at Moorhead and Fargo the width is many miles and the depth is 100 feet. In general, the clay is rather sandy and contains considerable carbonaceous material. It is colored yellow by oxidation near the surface, and is highly calcareous, containing both finely disseminated lime and medium-sized pebbles and concretions. Throughout most of the valley the clays are leached to depths of from 1 to 10 feet. Over the clay is a thin layer of black loam. Only the yellow subsoil has been employed as yet for the manufacture of brick. This leached portion usually is quite free from the limestone pebbles and is less plastic and dries more safely than the lower portion. On account of the tendency to crack in drying, the lower clay is spoken of as a joint clay, and is very little used. Very little work

has been done on the joint clay, though it forms much the largest portion of the whole mass. The work on preheating, referred to in Chapter II, may be suggested as a method by which this defect can be corrected with commercial success. Across the line in North Dakota, where the material is of exactly the same quality as in Minnesota, a sample of the joint clay was taken and tested by the North Dakota Geological Survey, as shown by their Fourth Biennial Report.

It contains more clay substance than the yellow clay, although considerable fine sand is still present. It takes 29.6 per cent of tempering water for the best plasticity, which is good. The tensile strength is 255 pounds, and the air shrinkage is 5.3 per cent. In burning its behavior was as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
010	Orange Pink	0.0	30.3
05	Pink	0.3	30.9
03	Pink	0.0	30.3
01	Green	(failed by cracking)	10.1

Incipient fusion occurred at cone 02, vitrification at cone 1, and viscosity at cone 2. The bricklets were all strong. This clay alone would probably be valueless, but because of its good plasticity and high binding power, it could be mixed with a sand or a sandy clay and worked by the stiff-mud process for the manufacture of common brick. Several tests have been made for the use of this clay as a paving material. In some cases, with a correct mixture, fair results are obtained.

Summarizing the properties of these clays attributed to the action of Lake Agassiz and the Red River, we have the following averages. Thirty per cent of water is required for molding. Tensile strength is 100 pounds per square inch, but somewhat reduced by rapid drying. Air shrinkage is over 6 per cent, and the fire shrinkage increases from 3 to 7 per cent during vitrification. The absorption, meanwhile, decreases from 24 to 10 per cent. Vitrification begins at cone 01 (2066° F.), and viscosity is reached at cone 4 (2210° F.). Analyses are reported in the discussion of Polk County.

Strength tests have been conducted on brick from these Lake Agassiz deposits by E. Brydone-Jack, of Winnipeg, with an average strength of 2,860 pounds per square inch, a minimum of 2,365 pounds per square inch, and a maximum of 3,760 pounds per square inch on five brick tested. Five hollow brick gave an average of 706 pounds per square inch. Surfaces of the brick were planed off and pressed between blotting paper. Bricks manufactured from the Red River silts were tested in the Engineering Laboratory of the University with the following results: Crushing strength was 1,300 pounds per square inch. The absorption was 33.3 per cent and the modulus of rupture 364 pounds per square inch.

Recent deposits

RIVER CLAYS

The chief deposits discussed under this heading are those along the Minnesota River, but the Mississippi and St. Louis rivers have also considerable deposits of this type, and many of the smaller streams contribute smaller amounts. The deposits along the Red River of the North are discussed under a separate heading.

Summarizing the properties of the alluvial clays in Minnesota, we have the following averages. The plasticity is usually rather low, and the clays are nearly always sandy. In the average case, 25 per cent of water is required for molding, and the tensile strength is about 100 pounds per square inch, even when the clay is rapidly dried. The air shrinkage will average 5 per cent and the fire shrinkage from 2 to 8 per cent during vitrification. The absorption of the brick is about 19 per cent when it first becomes very hard, which occurs about cone 02 (2030° F.). Viscosity is reached at cone 4 (2210° F.). An analysis is reported in the discussion of Goodhue County. A fairly representative sample of bricks made from alluvial clays of the Minnesota River were tested at the Engineering Laboratory of the University. The crushing strength is over 1,300 pounds per square inch, even when the bricks are wet. The absorption is 20.8 per cent. Tests of similar material by the City Building Inspector of Minneapolis gave the following figures: Wire-cut common brick, 1,497 pounds per square inch; sand-mold common brick, 1,560 pounds per square inch; wire-cut hard burned brick, 6,010 pounds per square inch.

LAKE AND SWAMP CLAYS

For the most part the recent lake clays are not expected to be of very different quality from the clays of glacial lakes of glacial time. The surface of the surrounding country still consists of the same red and gray drift, which furnished the sediments just after glacial time. Some slight differences, however, may appear, since during glacial time the melting ice furnished immense volumes of water such as are not duplicated by the more recent time. Erosion and filling of the lake beds have also had a tendency to decrease the size of the bodies of water.

Summarizing the properties of the recent lake clays, we have the following averages. The water required for molding is 26 per cent. The tensile strength is a little above 100 pounds per square inch, and is only slightly less if the clay is rapidly dried. The shrinkage on drying is 6 per cent, and the fire shrinkage ranges from 2 to 6 per cent during vitrification. The absorption at the beginning of vitrification is 15 per cent. Vitrification occurs between cone 04 and cone 2, a range of about

200°. (See Figs. 10 and 11.) Sample analyses are found in the discussion of Freeborn County. The City Building Inspector of Minneapolis has made tests on hollow brick and tile made from one of these lake clays which burn salmon at low temperature, and cream color if burned steel hard. The hollow tile gave an average of 230 pounds per square inch of crushing strength, while the hollow brick had an average strength of about 260 pounds per square inch. A test by the Engineering Department of the University on some brick made with three vertical holes, to decrease weight, showed the brick to have a strength of 3,000 pounds per square inch. The modulus of rupture was 374 pounds per square inch and the absorption was 31.4 per cent.

CHAPTER VI

DISTRIBUTION OF TYPES OF CLAY IN MINNESOTA

The types here considered are those distinguished by their physical properties. The total production of clay products of all types in Minnesota in 1910 had a value of over $1,900,000.

REFRACTORY CLAYS

The *Archean* residual clays of refractory character outcrop in the neighborhood of Redwood Falls, Redwood County, New Ulm, Brown County, and at Richmond, Stearns County. There is every indication that these clays extend under the drift from one of these localities to the other, and widely to the west to many points where well records show white clay. They may reach 50 or 100 feet in thickness. Some begin to vitrify below cone 10, but are undeformed to cone 32. Washing would improve the color and raise the melting point of most of them.

The basal *Cretaceous* clays seen from Bowlus, in Morrison County, to Redwood Falls, Redwood County, are the best refractory clays developed. As they outcrop at Richmond, Mankato, and elsewhere, they are quite certainly extensive under the drift. No doubt the well records mentioned in the preceding paragraph refer in part to these clays. The greatest thickness recorded is 18 feet at Birch Cooley, near Morton, Renville County. The best material is that near Redwood Falls. That farther north is more ferruginous, but nevertheless refractory.

The higher Cretaceous clays at several points in Brown County, and from there to Ottawa in Le Sueur County, are also highly refractory. An attempt was once made to use the clay at the latter place, but the plant is now idle. Conditions seem favorable for its success. Along the Cottonwood River in Brown County, notably in Sec. 36, T. 110 N., R. 31 W., the clay is of especially high quality. Much of the country between and around these places may be worth more careful prospecting than it has received.

SEMI-REFRACTORY CLAYS

VITRIFYING CLAYS

Cretaceous shales are the only ones in this class, and those mined for the stoneware and sewer pipe works at Red Wing are the best known. Their vitrifying behavior is exceptionally good, but they fuse at such low temperatures as to leave them very near the non-refractory class. The deposits which are worked at Clay Bank and Belle Chester are

disturbed and apparently transported remnants of a larger formation which must have existed some distance northwest. If the main body still exists, it is covered with drift and is not known. Careful observations should be made and records kept of all drilling in the region. The deposit at Belle Chester was discovered a relatively short time ago by drilling where the drift gave evidence of some included clay brought from the same direction as that at Clay Bank. Drilling should be continued in both directions, though it is likely that the main sources of the clay may now be more deeply covered with drift than the transported masses. These clays are the most valuable yet developed in the State and with new discoveries may continue to be the most valuable.

West from these points the Cretaceous shales in many places are non-refractory, but the character of two deposits, one at Austin, Mower County, and one near Essig in Brown County, shows that the conditions for the development of the type were widespread and there is every reason to expect similar clays to be discovered here and there under the drift over any part of the counties between. The clay at Austin is now being explored by drilling. That near Essig is excellent, but at present somewhat inaccessible and of uncertain quantity.

CLAYS THAT MELT SUDDENLY

The *Huronian* residual clays near Bowlus in Morrison County, and the Huronian paint rock on the Mesabi Range are to be classed here.

NON-REFRACTORY CLAYS

VITRIFYING CLAYS

Aside from the smaller formations of no importance as clays, the great formations yielding this type of clays are the Decorah shales, the Cretaceous shales, and the Pleistocene red drift. These without exception have a good range of vitrification. Recent lake clays also show a fairly good range. Some other Pleistocene and Recent clays may have a good range, but most of them have not. The vitrified brick and drain tile produced in Minnesota in 1910 had a value of nearly $250,000.

The *Huronian slates,* when mixed with a small amount of red drift clay, will show a range of vitrification which makes it possible to burn them to excellent fancy brick. They outcrop conveniently to Duluth at Carlton, Thompson, and up and down the St. Louis River.

The shales of the great red sandstone of Keweenawan or Cambrian age outcrop so rarely and are so thin that they are not likely to be developed, though the quality seems to be excellent.

The *Decorah shale* of the Ordovician is uniformly of excellent

The clay becomes too hard to scratch with a knife at cone 02 (2030° F.), and does not become viscous at cone 5 (2246° F.). These tests show an excellent quality of clay with a range of vitrification considerably over 200°. One sample taken from the eastern end of these lake deposits along Rice River showed a rather lower tensile strength and a lower temperature of fusion. This clay reached viscosity at cone 01 (2066° F.). It should be safe to burn these clays thoroughly hard and perhaps to vitrification. So far only common brick have been made from them, but their great extent and accessibility should make them the subject of further experiment. The fact that they are gray laminated clays, but burn to a red color, would indicate either that the upper portion of the deposit has been greatly leached of lime, or that the red drift has contributed largely to their formation.

ANOKA COUNTY

Types of clay, Pleistocene...............c) Gray lake and river clays
b) Red drift
a) Gray drift

At the lower end of the southern panhandle of the county, where it adjoins northeast Minneapolis, there is a very extensive deposit of gray clays. This extends along both banks of the river well down into the city of Minneapolis, but, on account of the value of the property within the city limits, there is an increasing tendency to crowd the brick-making industries north into Anoka County and outside the city limits in North Minneapolis. The detailed description of the clay will, therefore, be given here at the beginning of the chapter in connection with Anoka County rather than later in the discussion of Hennepin County.

The bed rock formations along the Mississippi River north of Minneapolis are the St. Peter sandstone and overlying it in the bluff, the Platteville limestone. Over this the hillsides show first the red drift, and above that the gray drift. Both the drift and the bed rock have evidently been eroded by the glacial Mississippi River, resulting in the formation of a wide channel, which, during glacial times and probably continuously since then, has been the site of the deposition of these gray laminated clays. The relations of the different formations at this point are illustrated in Fig. 7. The entire mass of stratified clay undulates at angles of 10 to 20 degrees. The clay is essentially the same from top to bottom, having been opened to a depth of over 30 feet at several brick yards. The curious internal structure seems to have been caused by eddying motions in the water which came down the river periodically. Some of the layers are singularly contorted in their finer laminations. (See Plate

A. RED DRIFT BELOW GRAY DRIFT AT COON CREEK. THE STEAM SHOVEL IS LOADING GRAY DRIFT ON DUMP CARS. IN THE FOREGROUND ARE SEEN THE MARKS OF TEETH OF THE STEAM SHOVEL ON THE RED DRIFT CLAY, WHICH IS USED.

B. GRAY LAMINATED CLAY, USED IN NORTH MINNEAPOLIS.

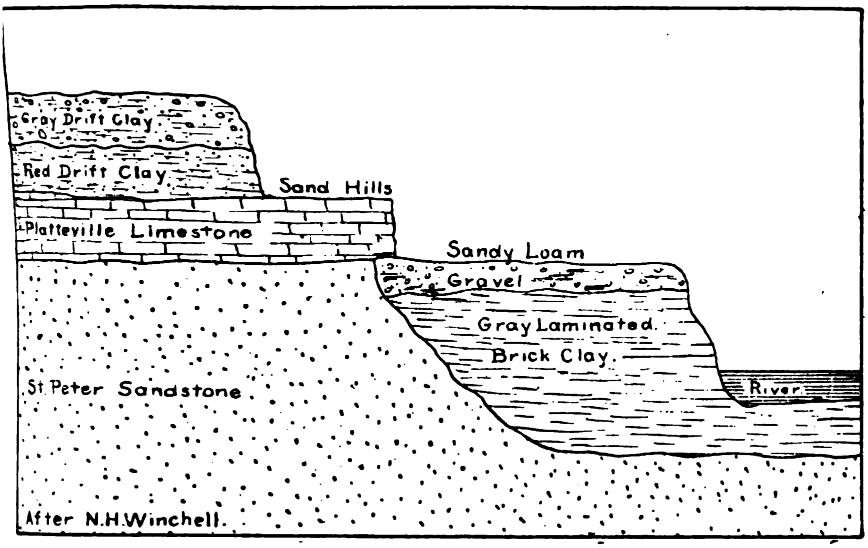


FIGURE 7. SECTION SHOWING THE OCCURRENCE OF GRAY LAMINATED CLAY IN NORTH MINNEAPOLIS.

V, B.) The sandiness of the deposit varies erratically, and most of the pits opened are said to be pockety. Although it is stated above that the clay is uniform, such uniformity is limited to the larger features, and the clay products manufactured are uniform only if the clay is mixed from several parts of a reasonably large exposure. When this is done, the products are excellent. The clay slakes at once and is highly plastic, requiring 24 per cent of water for molding. Its tensile strength is nearly 200 pounds per square inch and its air shrinkage is about 4 per cent. As tested by the U. S. Bureau of Standards, it behaves as follows: It works well in the auger machine without lamination. Burned colors are buff to greenish at higher temperatures. The porosity is over 30 per cent up to cone 05, and fusion occurs suddenly with a decrease in porosity to 1.6 per cent, at cone 02. It is to be recommended for common brick and fireproofing.

Work began in 1879, and since then eleven plants have been built and have been actively at work. Most of them produce cream-colored brick, for which there is a considerable demand in the Twin Cities for backing of brick walls and for interior work generally. At most of the plants the bricks are not burned very hard, but serve the ordinary purposes very well. Most of the plants have a capacity of approximately 40,000 bricks per day, and operate through the whole season until frost. Probably nine-tenths of the brick are burned in large scove kilns. To effect economy in labor and fuel the Minneapolis Brick and Tile Com-

pany installed a continuous kiln with a gas producer for firing at their plant on the west side of the river. Thus far it is not so much more economical as to be used in preference to the scove kilns which the same company also operates on the east side of the river. The Northwestern Fire-proofing Company, which has the most northern plant now operating on the east side of the river, have practically abandoned the production of common brick and have devoted their energies and their plant to the production of hollow ware, with great success. The proximity of the Minneapolis saw mills has been a factor in their success. They furnish a convenient supply of sawdust for mixing with the clay to render the finished product much lighter than it would otherwise be. The company has now a stock pile of sawdust and a thoroughly explored bank of clay sufficient to assure them successful operation for many years. They are frequently adding to the capacity of the plant by increasing the facilities for drying and by so arranging their stock of clay that the machinery can be kept running earlier in the spring and later in the fall. Work was begun at this plant in 1875, and shows every sign of continued prosperity. The Minneapolis Brick and Tile Company also produce hollow ware in their continuous kilns. The quality of the products made from this clay is indicated by the following tests. The Minneapolis Building Inspector reports the average strength of 10 bricks from one plant as 2,968 pounds per square inch, with a minimum of 1,600 pounds and a maximum occurring in a brick from the center of the kiln, of 5,080 pounds per square inch. Three other series of tests on bricks from this deposit gave an average strength of 1,560 pounds per square inch, with a minimum of 631 and a maximum of 2,770 pounds per square inch. A series of 5 bricks from one plant gave an average strength of 2,588 pounds per square inch. The general average of all the brick tested at this office from the North Minneapolis deposits is over 2,000 pounds per square inch. One test by the Minneapolis Building Inspector on a hollow tile about 4 x 8 x 17 inches, with 6 one-inch openings through it lengthwise, gave a strength of 604 pounds per square inch.

The following partial analyses of the clay are available:

Analyses of Gray Laminated Clays of Minneapolis

	1	2
Silica	50.65	54.17
Alumina	10.25	16.67
Iron oxide	4.00	8.06
Titanium oxide	0.52	.....
Magnesia	4.68	.....
Lime	10.65	.....
Soda	1.44	.....
Potash	1.96	.....
Moisture	1.20	.....
Ignition	14.40	.....
	99.75	.....

1. Pit of Minneapolis Brick and Tile Co.; west of the river, F. F. Grout, analyst.
2. Pit east of river. Analysis reported by C. P. Berkey.

The Experimental Engineering Department of the University report the strength of the North Minneapolis brick as follows: Five dry brick had an average crushing strength of 1,940 pounds per square inch and wet brick were only slightly weaker. The modulus of rupture is 411, and the absorption 29.7 per cent. There is some variation in the product at different yards.

While it has been proved in actual practice that these clays are capable of producing excellent common brick and about the best fire-proofing of any clays in the Northwest, and in years past have even been used for pottery, it is recommended that attempts be made to mix this clay with some of the other clays available in the neighborhood in the attempt to produce vitrified ware which will stand burning to a harder product. Such products are greatly in demand in the Twin Cities and are now imported from other states.

The Minnesota Paving Brick Company has an extensive plant at Coon Creek, where the red drift is known to be 40 feet thick and is explored over 200 acres with an overburden of 20 feet of gray drift. (See Plate V, A.) As dug from the ground, it contains a small proportion of pebbles and bowlders, but these are not as numerous as in the average of the red drift throughout the State. None of the pebbles consist of limestone except in the overlying gray drift, which is discarded. The pebbles which do occur in the drift would be quite sufficient to ruin it for ceramic purposes unless crushed or removed. At the Coon Creek plant all the clay dug is put through a double series of conical rolls by which a large proportion of the pebbles are removed, and the rest are crushed to a size that renders them practically harmless. A sample of the clay was taken from material passed through these rolls. The clay slakes quite promptly and shows a fairly high plasticity, requiring 24 per cent of water for molding. Its shrinkage is 5 per cent and its tensile strength is nearly 100 pounds per square inch, though somewhat less if rapidly dried. As tested by the U. S. Bureau of Standards, it behaves satisfactorily on vitrification, the porosity decreases from 32 per cent to .4 per cent before melting and is less than 5 per cent through a range of about 100° F. The color changes from red to chocolate at vitrification.

The Coon Creek company has a plant making use of a steam shovel and 6 large down-draft kilns, with a total capacity of about 40,000 brick per day. The product of the plant is largely used by the Great Northern Railway in the construction of their station buildings and the paving for their station platforms. Some well-vitrified brick are roughened in imitation of klinker brick for fancy building material and some kept smooth for paving. At Minot, North Dakota, a platform was built partly with these brick and partly with the famous Purington brick, from Galesburg,

The gray drift is thick over most of the county, and in part of the area : silts of the Red River Valley have smoothed the topography by filling the depressions of the drift sheet under deposits which increase in ckness to the northwest. Both the silts and drift require the removal limestone pebbles to yield workable clay.

At South Bemidji, in a very favorable situation as regards shipping ilities, the south shore of a lake which is formed by the expansion of a er, contains blue and yellow clay of a common laminated type. It has n used at a medium-sized brick yard at South Bemidji for common ck. The deposit covers many acres and is exposed to a depth of 20 t, but is covered more or less deeply with very sandy overburden. At : present location, from 4 to 8 feet of sand are being removed. Some id is occasionally used in tempering the clay. The brick now visible the kilns look as if an attempt had been made to mix the yellow clay, iich is the chief body of the clay exposed, with the underlying blue clay. ie latter appears to have been very plastic and, as it is dug in a moist, t solid condition, it did not mix well and a most decided auger structure apparent. The brick are badly cracked. Possibly a more thorough igging before they are transferred to the auger machine would remedy is defect. Otherwise it is recommended that the two kinds of clay be ied separately. It should be possible to make excellent products from is deposit.

North of Bemidji, the shores of Bemidji Lake are composed of a more recent lake deposit which has been left exposed by a gradual lowering of the lake level as its outlet has been eroded. This particular deposit is highly calcareous, and it was investigated to ascertain whether it is suitable for cement. A partial analysis by F. F. Grout is as follows:

Insoluble, iron and aluminum oxides	65.90
Magnesia	5.10
Lime	12.20

The lime and magnesia existing in the form of carbonates, make up about one-third of the material, but are not sufficient to justify its use for cement, especially as the magnesia is too large a proportion of the whole. The material would probably burn to a cream brick.

BENTON COUNTY

Types of clay, 1. Pleistocene ....b) Gray lake and river clay
a) Red drift

Northeast of Sauk Rapids, along Elk River, grayish yellow laminated clays outcrop here and there, and these were once used for making brick.

The location is unfavorable for a large plant. Other deposits may be found along the Elk or Mississippi rivers, but most of the county exhibits only red drift and outwash.

BIGSTONE COUNTY

In Bigstone County, the only clays known are in the gray drift. These are of the usual type and require cleansing before use. Archean residual material is found at 250 feet in a well near Johnson.

BLUE EARTH COUNTY

Types of clay, 3. Recent................Alluvium and swamp clays
2. Pleistocene ....Gray drift
1. Cretaceous clays

Five miles south of Mankato, in Sec. 35, the Cretaceous overlies the Jordan sandstone and underlies the drift along the banks of the Le Sueur River. The drift is from 10 to 20 feet thick, the Cretaceous from 30 to 40 feet thick. The crumpled condition of the Cretaceous deposits and the irregularly lenticular form of the clay lenses which occur in them indicate the probability that the whole series was distorted by the crowding of the glacial ice. Samples were taken from some of the smaller clay lenses, which are rarely over a foot thick, but were found outcropping for several hundred yards along the cliffs. The clay is very fine grained and chalky, though stained with iron in a few places. It does not slake when dropped into water. It is extremely lean and requires 27 per cent of water for molding. Its air shrinkage is about 1 per cent. At about cone 3 (2174° F.), it becomes so hard that it cannot be scratched with a knife. It is highly refractory and will stand a temperature of cone 33 (3254° F.) without deformation. It remains nearly white in color, varying from tints of buff to creamy brown. About 20 years ago the Pauline Pottery Company, of Chicago, tested the clay for the manufacture of fancy pottery. Mr. Joseph Kern, of Mankato, who owns the property, has some vases which were made in the experiment, which are very beautiful but very fragile. The phase which appears concretionary has 47.4 per cent silica, and 14.5 per cent water. Other outcrops near Mankato are believed to be Cretaceous shales.

Above the basal Cretaceous clays already described are a great many outcrops of alternating shale and sandstone with an occasional ferruginous craggy conglomerate. These various occurrences have been described by Warren Upham,[1] but most of the clay beds are rather thin and their extent is not well determined. (See Figs. 5 and 6.) Their character is indicated

[1]Upham, Warren, Minn. Geol. and Nat. Hist. Survey, Vol. 1, pp. 432-9.

by a sample taken in Le Sueur County discussed below. They are worthy of further exploration. Analyses are given in Table III, page 45.

The gray drift covers most of the county and shows the common characters. A sample was taken just southwest of Lake Crystal on the Omaha Railroad, where the deposit, of considerable size, is known to be 30 feet thick. Gravel was not as abundant at this point as in the average of the gray drift. After crushing the clay to 40-mesh it was found to have the following properties. Its plasticity was low, but required 24 per cent of water for molding. The tensile strength was over 150 pounds per square inch, even when the clay is rapidly dried. The shrinkage was 4½ per cent. Burned at the Minnesota School of Mines Experiment Station, it gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	......	......
03	Salmon	1	20
02	Salmon	1	19
1	Salmon	3	14
2	Brown	6	10
4	Brown	......	......

Up to the temperature of cone 03 (2000° F.) the particles of lime remaining in the burned brick cause its rapid disintegration on exposure to the air. The clay became too hard to scratch with a knife at this temperature and became viscous at cone 4 (2200° F.). Three plants have been started to make use of the drift in this neighborhood. None of them is now at work. Success would depend not only on market conditions, but on some method of removing limestone pebbles.

At Garden City and vicinity similar gray drift contains more than the usual proportion of limestone pebbles.

Five miles southwest of Mankato is a deposit on the farms of Mr. Joseph Kern and Mr. Frank Pearson, which extends over several acres to a depth of several feet. Near the surface the lime pebbles of the drift are less abundant than in the average of the gray drift. The clay slakes in 3 minutes and is highly plastic, requiring 23 per cent of water for molding, and showing a shrinkage of 5 per cent on drying. Its tensile strength was 100 pounds, but rapid drying affected this quite seriously. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	1.0	15
03	Salmon	1.5	14
01	Red	2.0	13
1	Red	5.0	10
2	Red	6.0	4
5	Brown	......	......

The clay becomes too hard to be scratched with a knife at cone 03 (1994° F.), and reaches viscosity at about cone 3 (2174° F.). If the economic conditions are found favorable, this clay is certainly capable of yielding a good grade of brick and tile. This overlies the pit formerly worked for Cretaceous clay of refractory grade and about worked out.

At Mapleton the entire region is covered with the common type of gray drift, with the average number of pebbles.

Near Rappidan, along the Milwaukee Railroad, near a bridge across the Le Sueur River, the whole country is covered with the usual type of gray drift. The upper part of the drift has been leached and is somewhat better clay than the main body. The clay slakes in 2 minutes, is highly plastic, requires 22 per cent of water for molding, and shrinks less than 5 per cent on drying. Its tensile strength is nearly 200 pounds per square inch even when rapidly dried. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	22
01	Salmon	4	18
2	Brown	7	8
4	Brown	......	......

The clay becomes too hard to be scratched with a knife at cone 06 (1886° F.), and viscous at cone 3 (2174° F.). It might be used without as extensive a treatment for the removal of the lime pebbles as is undertaken at Hutchinson. The market conditions are favorable, though throughout the southern part of the State there is competition from the plants in Iowa.

Recent alluvium is found at many points along the Minnesota River and some of its tributaries, such as the Le Sueur. Two and a half miles west of Mankato, a brick yard is in operation on alluvium of the Minnesota River, of which from 6 to 12 feet is workable and extends along the river in a flood plain of very great extent. It is typical of the material between Chaska and New Ulm and even beyond. The clay slakes at once and its plasticity is very low. It requires 22 per cent of water for molding and shrinks 4 per cent on drying. Its tensile strength is 175 pounds per square inch, whether it is slowly or rapidly dried. It is rather sandy, and some care has to be used to exclude even the coarse gravel which occurs in irregular layers. As burned at the Minnesota School of Mines Experiment Station it gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0.0	24
02	Salmon	0.5	22
1	Brown	7.0	10
3	Brown	8.0	6
5	Brown	......	......

The clay burns steel hard at cone 02 (2030° F.), and is near viscosity at cone 5 (2246° F.). The plant is making an excellent quality of common red brick by a soft-mud process at the rate of about 4 million per season. Another favorable place for the development of this alluvium near Mankato is about 40 rods north of the city limits, along the Omaha Road, where the river basin extends to a width of 3 or 4 miles.

Three miles from the station of St. Clair, on the south bank of the Le Sueur River, is a swamp of 40 acres or more, which has been drained by a ditch. It exposes a clay about 15 feet in thickness, the upper part of which is yellow and the lower blue-gray. A few feet of peat overlies the clay in part of the swamp. The clay seems to be exceedingly pure. It slakes in 6 minutes and is highly plastic, requiring 30 per cent of water for molding. Its tensile strength is about 80 pounds per square inch and its air shrinkage is 8 per cent. In burning it becomes hard and is salmon-colored at cone 06 (1886° F.). Its absorption at this temperature is 16 per cent. There is enough organic matter present so that, if rapidly heated, the bricks would swell and crack and develop black cores, but, if slowly heated and thoroughly oxidized, good red brick can be produced, and viscosity is not reached below cone 1 (2100° F.). All conditions seem to be favorable for the manufacture of brick and tile, except that the deposit is located about a mile from the railroad.

Near Good Thunder in this county about a half mile south of the station, is a deposit in a swamp covering many acres, which had been worked up to 1904 for many years. The clay is quite free from limestone pebbles, and the brick made from it have stood the test of service for nearly 30 years in some of the buildings in the town. An analysis was made by F. F. Grout for Dr. J. T. Schlesselman some years ago.

Surface clay

Silica	70.29
Iron and aluminum oxides	18.71
Magnesia	1.35
Lime	2.02
Soda	0.56
Potash	1.87
Moisture	2.15
Ignition	3.60

This is probably fairly characteristic of the bog deposits throughout much of the State. They may contain constituents of the wind-blown loess, but are largely made up of the wash from the neighboring hillsides.

The humic acids developed in the bog tend locally to leach out the soluble lime and iron, but generally enough iron is left so that the clay will burn red.

BROWN COUNTY

Types of clay,	4. Recent	Alluvium
	3. Pleistocene	Gray drift
	2. Cretaceous	b) Shales
		a) Basal clays
	1. Archean	Residual clay

Mr. Oliver Bowles, who made a study of this county, contributes the following data:

The only working plants in Brown County are at Springfield and New Ulm. The plant at Springfield is supplied from an extensive bed of laminated Cretaceous shale, while the plant at New Ulm employs the extensive brown and yellow clays deposited along the Minnesota River, sometimes adding some gray laminated clay from the bluffs near by. The gray drift over most of the county contains many pebbles, chiefly of limestone. Since clays of much better quality exist in this county, the plants which used it are abandoned and no further development of the gray drift is to be recommended.

In Sec. 36, T. 110 N., R. 31 W., along the banks of the Cottonwood River, near water level, is an exposure of about 10 feet of a white clay which extends several feet below the bed of the river, but its extent has not been fully determined. Outcrops were seen for a distance of one-half mile along the banks. A large part of the clay is very gritty with coarse angular quartz. The mixture of this quartz with the clay gives the appearance of a granitoid texture and indicates that this is residual or colluvial. Some parts of the outcrop show very little of this quartz, and some are highly colored in variegated tints, but by far the largest part of the formation is clear white in color. This was recently described by F. W. Sardeson.[1] At the best outcrop the following section was recorded.

Gray drift	40 feet
Cretaceous clay and sand, disturbed	8 feet
Cretaceous white gritty clay	12 feet
Archean rotted granite	4 feet to water level

[1]Sardeson, F. W., The Redstone Quartzite: Bul. Geol. Soc. Am., Vol. 19, p. 223.

The clay slakes in 3 minutes, is highly plastic, and requires only 19 per cent of water for molding. Its tensile strength is not much over 70 pounds per square inch. Its air shrinkage is 5 per cent. As burned by the Minnesota School of Mines Experiment Station it gives the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Light red	1	15
1	Red	1	15
4	Red	2	13
5	Red	......	......
13	Light brown	......	......

The clay becomes too hard to be scratched with a knife at cone 06 (1886° F.), and, while thoroughly vitrified, it is still undeformed at cone 13 (2534° F.). This sample, representing as nearly as could be judged the average of the formation, contained about 50 per cent of sand too coarse to pass a 60-mesh sieve. Over 30 per cent was fine enough to pass the 200-mesh sieve. If this is at all suitable for the production of high-grade chinaware, it should be possible to make a commercial success of a washing process to remove the quartz and some of the coloring matter.

In Sec. 36, T. 110 N., R. 30 W., is another outcrop of so-called pottery clay. This is part of the Big Cottonwood formation described by Sardeson.[1] It is not particularly well situated for shipping. It outcrops about two miles from where the Minneapolis and St. Louis Railroad leaves New Ulm going south. The outcrop rises 6 or 7 feet above water level in the Cottonwood River and extends an unknown distance below water. Twenty or thirty acres appear to be underlaid with the material. As tested by the Bureau of Standards at Pittsburgh, the properties are as follows: The plasticity was satisfactory for working in an auger machine with 17 per cent of water. The drying shrinkage was 5 per cent. Burned colors were fairly white, but iron granules could be seen. The clay softens at cone 31½ (3200° F.). Machine-made brick had a tendency to check in burning, but this was not true of the hand-mold brick. This is an excellent refractory clay, and should be of value.

Mr. Aufderheide, of the brick plant at New Ulm, has made some fire brick of the material, described as from Sec. 36, which was refractory, but did not show a satisfactory strength after being repeatedly heated and cooled. No other attempts have been made to use these clays.

In the neighborhood of New Ulm, and across the river in Sibley and Nicollet counties, there are a great many outcrops which are

[1] Op. cit. p. 231.

worthy of more attention than they have received. In the city limits of New Ulm, in the southeast part of town, a pottery was established some 30 years ago and obtained its material from a bed from 4 to 8 feet thick of uncertain extent, but said to exist under the center of town with no more than 10 or 12 feet overburden. The clay slakes in 2 minutes, is highly plastic, and requires 20 per cent of water for molding. It has a tensile strength of 200 pounds per square inch and can safely be dried with artificial heat. The air shrinkage is less than 4 per cent. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Cream	0.7	14
03	Buff	1.0	......
1	Buff	1.4	12
5	Buff	......	......
12	Light gray	......	......

The clay becomes hard at cone 03 (1994° F.), and, while well vitrified, it does not seem to be near viscosity at cone 12. This deposit should be carefully studied to determine its extent.

Near the south side of town, near the Northwestern Railroad crossing over the Cottonwood River, shales occur to a depth of 40 feet extending over an unknown area, probably very great. The lower main portion is a rather soft gray clay, very favorably situated for development. It slakes very slowly, but is highly plastic, requiring 29 per cent of water for molding. Its tensile strength is 150 pounds per square inch, but rapid drying lowered this very materially. Its air shrinkage is 10 per cent. As burned by the Minnesota School of Mines Experiment Station, it gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	2	12.0
02	Salmon	4	7.0
01	Brown	5	3.0
2	Brown	5	2.6

The clay becomes too hard to be scratched with a knife at cone 05 (1922° F.), and is viscous above cone 2 (2138° F.). This is one of the most promising bodies of Cretaceous clay that have been investigated. Most of it is gray in color, and it can be traced through the various hills in the neighborhood. Boring and wells have revealed the fact that the clay extends over considerable territory where it is concealed by later deposits. The upper portion of the deposit is red and evidently calcareous, possibly contaminated with gray drift and possibly with Cretaceous limestone. It is certainly much less valuable clay, but this poor clay is thin and there is 40 feet of the gray

clay below. The extent of such clay is shown by an outcrop of similar character along the Cottonwood River in Sec. 31, two miles west of town, though at this point the drift cover is heavy and less than 10 feet are exposed.

Across the road from the New Ulm Farmers' Elevator on a property now used as a city park, is a third outcrop of shale which is red above and blue-gray below, and which can be followed along the bluff for considerable distance. Economic conditions are excellent and, if material underlying the less valuable property is similar in character, there should be room for some industrial development. The slaking and plasticity are about the same as in the other samples. The air shrinkage is 8 per cent. The clay burns salmon-colored and becomes hard at cone 05 (1922° F.). At cone 2 (2138° F.) it has become greenish gray and is at the point of viscosity.

An exposure much less favorably situated occurs near the brewery of the A. Schell Brewing Company. The physical properties of this material are not as good as those above reported.

Three or four miles south of Essig, on the Northwestern Railroad, an outcrop occurs along the Cottonwood River almost continuously for a mile, showing 6 feet above water level and existing for unknown depths below. It is white to gray and very plastic. The outcrops are not perfectly continuous and, as there seems to be a difference between the white clay and the gray which is associated with it, it may be that the white clay exists mostly in pockets. Both the white and gray clay slake in a few minutes and are highly plastic, requiring 23 per cent of water for molding. The tensile strength is well above 100 pounds per square inch, even after rapid drying. The air shrinkage is about 7 per cent and, as burned by the Minnesota School of Mines Experiment Station, they have the following characters:

White clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
010	Buff	......	......
06	Buff	1	14
01	Buff	4	8
2	Buff	5	6
3	Buff	......	5
5	Buff	......	......

At all of these temperatures the clay is hard and undeformed. The absorption changes indicate the progress of vitrification, but the clay will evidently stand a higher temperature, about cone 10 (2400° F.) without becoming viscous.

Gray clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
010	Salmon	......	......
06	Salmon	......	13.0
03	Salmon	3	8.5
2	Salmon	4	6.0
3	Salmon	......	......

This clay is likewise hard, but not viscous at the temperatures reported, but there is evidently enough organic matter in the gray clay to cause danger of the formation of black cores. In a rapid test the brick swelled and cracked at cone 3. Both of the clays, however, show an excellent range of vitrification (450° F.), and are valuable. The white clay has been tested by the Red Wing Stoneware Company with results that were reported as favorable, but the material has not been used because it is not very readily accessible. The overburden is thin and the clay outcrops in a great many places.

At Springfield, some 20 miles up the Cottonwood River from New Ulm, the A. C. Ochs Brick and Tile Company have developed a large body of Cretaceous clays just east of town along the Northwestern Railroad. The clay is 20 feet thick above water level and is known to extend over 20 acres. It is gray, thin-bedded, and contains both pyrite and limonite in concretionary masses an inch or two in thickness. Over most of the area it is covered with common gray drift. The proportion of sand is somewhat variable. The clay slakes in 2 minutes, is highly plastic, and required 29 per cent of water for molding. Its tensile strength is nearly 200 pounds per square inch, but is much less if the clay is rapidly dried. Its shrinkage on drying is about 7 per cent. As tested by the Bureau of Standards, a sample of especially rich plastic shale has the following characters: Auger lamination is serious and there is much danger of cracking on drying. The clay burns buff at low temperatures and is chocolate when vitrified. The range of vitrification is excellent. A porosity of less than one per cent is maintained for over 100° F., without viscosity. Fire shrinkage is less than 5 per cent. It is probably available for roofing tile, if warping can be avoided in drying. A special die might be successful.

The company has been operating for 20 years and has manufactured mostly hollow brick and tile, with a plant consisting of 8 kilns which when full would contain about 4 million bricks. Both soft-mud and stiff-mud brick are manufactured and the strength of the product is excellent. The Minneapolis Building Inspector has the following record: Three well-burned building tile of 91-inch cross section, two holes horizontal, gave an average strength of 965 pounds per

square inch. The degree of vitrification easily obtained would indicate that the material is suitable for paving brick, but the wearing qualities have not been tested and few of the bricks are made solid, as the central core makes them lighter for shipment and assists in drying without checking.

An area of similar Cretaceous clays outcrops west of Springfield. Its properties are probably very similar to those of the clay east of town. Mr. Ochs reports, however, that the other clay described is capable of making excellent sewer pipe, whereas that east of town is usually burned to a well-vitrified building block.

Although these different outcrops of Cretaceous clays vary in their properties, some of them are very promising, and there is much evidence that they are present throughout most of the southern part of the county, and are in some places 200 feet in thickness. Analyses are reported in Table II, page 45.

A mile and a half southeast from the center of New Ulm, river clay is known to a depth of 8 or 9 feet over several acres. The upper part of the deposit is dark brown, but the lower part is yellow and more plastic. There is no overburden except the sod, and the usual impurities are scattered patches of sand or even an occasional bowlder and some organic matter. The deposit has been used since 1875 for red brick made with a soft-mud machine which has a capacity of two or three million brick per season.

CARLTON COUNTY

Types of clay,	4. Recent	Alluvium
	3. Pleistocene	c) Gray lake clays
		b) Red lake clays
		a) Red drift
	2. Algonkian (?)	Red clastic series
	1. Huronian	Slates

At Wrenshall, gray lake clays are extensively developed. The town of Carlton as a railroad center has the best location if material were available, and it is hoped that the Huronian slates so prominent here may be made the foundation of some extensive industries with Duluth and Superior as the closest markets. But with the fancy product which doubtless could be made, it should be possible to ship to the Twin Cities and throughout the Northwest.

The Huronian slates outcrop in especially favorable situation along the St. Louis River from Cloquet to Carlton, in glaciated knobs projecting above the general level of the drift. These are not now

used, and the past attempts were not particularly successful. They are extensively metamorphosed and have developed a good secondary cleavage though they are not very satisfactory as roofing material. (See Plate II, B.) The variation from a graywacke to a slate is not regular and the folding and crumpling of the formation makes it difficult to predict exactly where good slates are available, but a hasty trip over the district makes it certain that there are many convenient places where the thickness is very great and there is no overburden. The hardness of the material would increase the difficulty of quarrying, but all other conditions seem to be favorable. The slate is of course non-plastic, has very little tensile strength and air shrinkage. It needs only 9 per cent of water for molding. At cone 5 (2250° F.) it is thoroughly vitrified and dark red in color. In 1892 a company was organized under the name of the St. Louis River Slate Brick Company. The superintendent of the company had a patent or secret process which he tested with considerable thoroughness, but nothing has been done for the last eighteen years. The brick produced were red pressed brick of excellent quality, and some are now standing in several Duluth buildings. One disadvantage of the brick was their high specific gravity which increased the freight rate per thousand brick.

A fancy brick could readily be made from this slate by the addition of some more easily fusible drift clays in the neighborhood. Laboratory tests indicate that the clay at Wrenshall which occurs in such quantity a few miles east, and the red bowldery clay so prominent in all the neighborhood around the west end of Lake Superior would be excellent for bonding clays. With 5 per cent of red clay, the mixture became so hard at cone 06 (1900° F.) that it could not be scratched with a knife, and was still undeformed at cone 5 (2250° F.). The color ranged from light to dark red between these temperatures, and the appearance changed from that of common red brick to that of a thoroughly vitrified paving brick. An experiment was made by mixing these clays without crushing the slate to the usual degree of fineness. With lumps up to ¼ inch in diameter, the popular rough appearance of a klinker brick was closely imitated. Fancy brick of this type would be in great demand in the cities at the head of the lake. By using the proper proportion of the fusible red clay, it is possible to get the rough lumpy brick to have the appearance of being glazed, and the excellent characters of the resulting product seem to promise well for this deposit.

Red clastic series. On the railroad above Fond du Lac is an out- of shale associated with the red sandstone of the western end

[Lake Superior. It is a soft, fine-grained red shale with a few small ray circular areas, which aside from the color do not appear particu- ırly different from the rest of the rock. A chemical analysis of this ›ck is as follows:[1]

Silica	48.92
Alumina	18.45
Ferric oxide	16.88
Ferrous oxide	0.57
Lime	0.70
Magnesia	3.68
Soda	0.48
Potash	1.32
Water	7.14
	98.14

Red drift, of the common pebbly character, was made use of some ears ago for red brick, just north of the town of Barnum. The ıtire region around Barnum seems to consist of pebbly clay, and ıe pebbles must be crushed before the clay will make satisfactory roducts. The clay slakes in 5 minutes, and has a fairly high plastic- y, requiring 21 per cent of water for molding. Its air shrinkage is ver 6 per cent, and its tensile strength is about 75 pounds per square ıch. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	2	11
02	Red	7	6
5	Red	......	......

he clay becomes hard at cone 04 (1958° F.), and seems to contain ıough organic matter so that, if rapidly heated, it develops a black ›re and swells greatly, but, if thoroughly oxidized, it will stand a mperature of about cone 2 (2138° F.). This is apparently a type [clay that is very widespread throughout the eastern part of the tate.

Deposits around the west end of Lake Superior show that dur- ıg the retreat of the ice the great basin was dammed across so that ater was raised to a level of over 300 feet above the present lake. n this lake, known as Lake Nemadji, the melting ice dropped red ebris and glacial rivers brought down and deposited various sedi-

[1]Minnesota Geol. and Nat. Hist. Survey, Vol. 5, p. 555.

ments. Water sorting resulted in the formation of some rich laminated clays, but floating ice contaminated some of the clays with bowlders. Streams from the gray drift areas in the west produced gray clays. The ice itself brought red bowldery clays.

The red bowldery clays have thus far been little used in Minnesota, but are worthy of more attention wherever sand or slate is available for mixing. The deposit in this county is known to be at least 60 feet in thickness, and extends across the county for many miles. The southernmost of the accessible outcrops is 4 miles east of Moose Lake, on the Soo Line. Especially favorable occurrences are at Holyoke, and it might be possible to develop a deposit within two miles of Wrenshall where the gray laminated clays are so well developed. The deposit is no doubt continuous between all these localities. It is characteristic of the clay not to show any pronounced lamination, or sandy layers such as are characteristic of most red glacial lake and river clays. The chief distinction between this and common pebbly red drift from the northeast, is the relative abundance of clay and some faint traces of stratification. There is also the fact that it is found on all sides of the west end of Lake Superior, where such a deposit would be expected if it had this origin. It has been spoken of as a "water-laid moraine." The clay slakes in 2 minutes, shows a very high plasticity, and requires 27 per cent of water for molding. Its tensile strength is nearly 100 pounds per square inch, but it cracks rather seriously if rapidly dried. The air shrinkage is 9 per cent. Burning tests indicate a range of vitrification of about 250° F. and the temperature of viscosity is 2100° F.

On account of the rather high shrinkage, a sample of the sand which occurs in the neighborhood and frequently overlies this clay directly, was mixed with the clay to ascertain whether a slight addition might improve the shrinkage and the range of vitrification. This proved to be the case and it is recommended that for hard burned common brick, plants should be located where a supply of sand is available. This is the clay, also, which was used in experimenting with the slates near Carlton for the manufacture of fancy rough brick. As it shows a lower cone of fusion than the slates, it serves very nicely as a sort of glaze and bond between the coarse grains of slate. Its plasticity also is a desirable quality when it is mixed with the non-plastic slates.

The gray laminated clays were washed into Lake Nemadji from the west and are most prominently developed in the vicinity of Wrenshall. They are not much contaminated with bowlders. (See Plate IV.) Five large successful plants are in operation, each with essentially the same type of clay, which here has been developed to a

depth of about 50 feet and explored to the depth of 80 feet. Near its upper surface for a few feet, it is more or less broken up and mingled with pebbles, but this condition disappears gradually with depth and the stratification becomes regular. The same gentle undulation visible in the laminated clay north of Minneapolis (described as in Anoka County) occurs here also. The clay when blue or gray makes a cream-colored brick, but the top part of the deposit has not only been disturbed physically, but apparently has been altered chemically by leaching so that its color is red and it burns to red brick. In the upper 10 or 15 feet the disseminated lime has apparently been segregated and is seen in the form of limey concretions which, however, are seldom so abundant as to be serious. The clay extends generally under the flat region, and is seen along the sides of many deeply cut ravines draining into the St. Louis River. It is about 300 feet above the flat on which Superior and West Duluth are located. The detailed structure of the clay is so similar to that of clays found along the Minnesota and Mississippi rivers that its development in interglacial times or soon after the retreat of the ice may be pretty confidently assumed. The lamination is evidently due to the same causes, but the occurrence of this deposit in a place where no river of the same general type is known and the wide extent of the deposit itself, are indications that it formed as a lake deposit rather than as a river silt. The clay slakes in 3 minutes, and shows a fairly high plasticity, requiring 23 per cent of water for molding. The air shrinkage is 4 per cent and the tensile strength is 175 pounds per square inch even when the clay is rapidly dried. Its qualities as shown by tests of the United States Bureau of Standards are as follows: The clay burns buff at low temperatures, but becomes greenish yellow when well vitrified. It has a short range of vitrification when the porosity drops from 42 per cent to nearly none in about 100°. This type of clay is not satisfactory for vitrified ware.

The various plants have a capacity ranging from 40,000 to 140,000 brick per day. Most of the brick are made with stiff-mud machines, although some find the soft-mud process more favorable. Very little hollow ware is produced. Red brick are turned out only when the upper layers of clay are carefully separated from the lower. If uniformly mixed, the 10 feet of red burning clay is not sufficient to affect the color of the 30 feet of cream burning clay. The average quality of the brick made at Wrenshall, as tested by the Experimental Engineering Department of the University, is as follows:

	Crushing Strength in Pounds Per Square In.		Modulus of Rupture	Per Cent Absorption
	Wet	Dry		
Soft-mud cream brick	2809	2166	982	29.4
Stiff-mud cream brick	2894	4762	926	21.7
Stiff-mud sewer brick	4474	5888	1409	18.5
Soft-mud red brick	3354	3233	679	14.9
Stiff-mud red brick	3770	5247	1189	13.3

River alluvium is deposited here and there along the St. Louis River. At Cloquet the river passes through a rather extensive flood plain or flat on which saw mills are located. Before the lumber yards became so extensive as to occupy most of the flat, a small brick yard produced some red, soft-mud brick, which were of fair quality, if one can judge from the buildings still standing at Cloquet. On the northeast side of the river a considerable portion of the flat is still unoccupied and was sampled to determine the quality of the silt of St. Louis River. It slakes at once and its plasticity is low. It requires 21 per cent of water for molding and its air shrinkage is 3½ per cent. Its tensile strength is over 100 pounds per square inch, even when it is rapidly dried. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Light red	1	19
02	Light red	2	18
1	Red	5	11
3	Red	7	7

The clay becomes hard at cone 02 (2030° F.), and reaches viscosity a little above cone 4 (2210° F.). It should be capable of burning to an excellent hard red brick, and the refuse from the saw mills should make the fuel problem an easy one.

CARVER COUNTY

Types of clay, 2. Recent ....Alluvium
1. Pleistocene ....b) Gray lake and river clays
a) Gray drift

The only place in Carver County where brick are being manufactured is at Chaska, on the Minnesota River. Gray laminated river clays of the glacial River Warren supply materials for the industry. The section at the clay pit consists of 20 to 40 feet of sand and gravel, stratified in the lower part, below which is dark gray clay to a depth of 100 to 200 feet. It is known to extend under the river for hundreds of acres. Its laminated character and geologic show that this clay is a deposit from the river, formed at a time

hen it was greatly swollen by the melting of glacial ice. When the tream was rapid, sandy deposits were mixed into the bank and ow are found as irregular pockets and "wells" and streaks, but so cattered that by mixing the product from different parts of the bank a uniform quality of brick may be produced. The clay slakes in one ninute, and shows a fairly high plasticity, requiring 28 per cent of water for molding. Its tensile strength is rather low, only one briquette showing over 100 pounds per square inch; and a test for the adhesion of two pieces of clay when pressed together shows very little strength. The average clay shows a shrinkage of 7½ per cent on drying, but when some of the particularly sandy layers were mixed in, this could be reduced o 4½ per cent apparently without injuring the product. The clay burns buff up to a temperature of viscosity, and can be burned hard with very ittle shrinkage. The absorption is over 20 per cent even in well-burned brick. Clay becomes hard at cone 02 (2030° F.), and viscous at cone 4 (2210° F.). The character is very similar when half the mixture is composed of the particularly sandy layers. Four plants using this clay are in successful operation. All are under one management and use essentially the same method. The capacity of the four plants varies from 45,000 to 140,000 brick per day. Last year 50 million brick were made at Chaska. Coal is the only fuel available, and a large proportion of the product are solid cream-colored brick, some of which are made in the soft-mud machine. Three of the plants have facilities for making hollow ware, and three of them are provided with steam shovels for winning the clay. Some of the products from Chaska have been tested by the Minneapolis Building Inspector. The results are as follows: Two sewer brick showed a crushing strength of 4,250 pounds per square inch. Four miscellaneous brick in one set gave an average strength of 1,600 pounds per square inch. A set of 14 brick, probably selected with some care (though this was not stated), had an average crushing strength of 2,635 pounds per square inch. Two hollow brick had a strength of 236 pounds per square inch. One hollow tile with three openings horizontally had a strength of 158 pounds per square inch.

The Experimental Engineering Department of the University of Minnesota obtained the following results on Chaska brick: Five soft-mud well-burned brick tested dry had an average crushing strength of 2,081 pounds per square inch. The modulus of rupture was 658 pounds per square inch and the absorption 22.2 per cent. The hollow building blocks have an average strength of 505 pounds per square inch. The modulus of rupture was 600, and the absorption 10.0 per cent. Wet brick had about the same strength as the dry ones.

The other clays of the county are of the gray drift and alluvium and are inferior, so far as known, to the deposits at Chaska.

CASS COUNTY

Types of clay,	2. Recent	Lake clays
	1. Pleistocene	b) Gray drift
		a) Red drift

Cass County is covered with gray drift except in its two southeastern corners, where the red drift is exposed. Possibly lake clays of value may be discovered near White City.

CHIPPEWA COUNTY

Types of clay,	3. Recent	Alluvium
	2. Pleistocene	Gray drift and gray laminated clay
	1. Archean	Residuals

Throughout the county, the gray drift, rarely free from pebbles, is abundant. At Montevideo it was abandoned for river clays and now the latter are abandoned also. Considerable clay is visible in the flat near the mouth of Chippewa River. Opposite Minnesota Falls are some small outcrops of clay residual from granite. These are not likely to be of much importance. N. H. Winchell reports[1] the same from Tunsberg. O. E. Meinzer reports well records[2] showing 70 feet of white clays, Cretaceous and Archean, at Montevideo, at a depth of several hundred feet.

The gray drift opposite Granite Falls was freshly exposed by a railroad cut, deep enough to reach unweathered gray drift below the yellow drift. (See Fig. 2.) Both the yellow and the gray drift are well supplied with limestone and other pebbles and contain about the proportion of sand found in the Hutchinson material. The clays slake in 2 minutes and are highly plastic, requiring 17 per cent of water for molding. The tensile strength is about 150 pounds per square inch and the shrinkage on drying less than 4 per cent. These samples require a temperature for vitrification slightly above the average.

About 5 miles northeast of Appleton, and a mile east of the Great Northern Railroad, the digging of a well has revealed a plastic blue clay which is apparently of the laminated type. The clay slakes at

[1]Winchell, N. H., Final Rep. Minnesota Geol. & Nat. Hist. Survey, Vol. 2, p. 213.
[2]Meinzer, O. E., Water resources of Southern Minnesota: U. S. Geol. Survey. Water-Supply Paper, No. 256, p. 153.

once and shows a high plasticity, requiring 34 per cent of water for molding. Its air shrinkage is 4 per cent and its tensile strength is over 150 pounds per square inch, though rapid drying is injurious. Burning tests proved it to be of very poor quality. The brick burns salmon color and shows very little shrinkage up to the temperature of cone 02 (2030° F.), where it has an absorption of 28 per cent. At cone 01 (40° higher) the shrinkage increased to 16 per cent, the absorption decreased to 2 per cent, and the clay is viscous. It is certainly not safe to burn the clay hard.

CHISAGO COUNTY

Types of clay, 2. Pleistocene.............c) Red lake and river clays
b) Gray drift
a) Red drift
1. Cambrian..............Dresbach shale

At Rush City a plant operating for several years made red brick from till. Later a particularly good clay was developed 1½ miles south of town. This is apparently to be classified as the outwash from the front of the ice sheet. It may have formed from the ice sheet which brought in the gray drift, but the gray drift throughout this county is rather thin, and enough material from the northeast has been incorporated into this outwash so that it burned red, and is here classed as part of the red drift. The clay slakes at once, and is highly plastic, requiring 27 per cent of water for molding. The tensile strength is between 50 and 75 pounds per square inch, and the air shrinkage between 5 and 6 per cent. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	0	20
05	Salmon	0	18
01	Red	5	10
3	Red	7	6
4	Red	......	......

The clay becomes too hard to be scratched with a knife at cone 05 (1922° F.), and is apparently not close to viscosity at cone 4 (2210° F.). It has thus a range of vitrification of about 300 degrees or more, and is capable of being burned to a very hard and excellent product. Brick have been made here for several years and a spur track was laid from the Northern Pacific Railroad half a mile away. It is claimed that the work was abandoned on account of the difficulty of getting expert men to carry on the work, but if the qualities of the

clay are as excellent as they appear to be, and there is any favorable market, it seems unfortunate that this plant has been abandoned.

Hills of gray drift cover a large part of the county and constitute the most eastern extension of this type of material. A sample was taken at Center City where the exposure is 40 feet thick. The clay slakes in 2 minutes, and is highly plastic, requiring 19 per cent of water for molding. Its air shrinkage is less than 4 per cent and its tensile strength is over 150 pounds per square inch. As compared with the material profitably used at Hutchinson, the clay at Center City is a trifle more sandy, containing 33 per cent instead of 30 per cent of sand. The difference should not be one of any importance, as the range of vitrification of the clay is essentially the same.

At North Branch a small brick yard was started many years ago in Secs. 14 and 15, just west of the town, making use of some patches of red drift which come to the surface here and there through the gray drift which covers it in most places. At Sunrise the material is evidently similar and was used in 1856. Red laminated clay also is exposed near Sunrise. At Taylors Falls, red laminated clay occurs on the Wisconsin side, but on the Minnesota side it is covered by gray drift.

The Dresbach contains a thin shale layer in the bluffs near the Dalles at Taylors Falls, and, though of fair quality, it is probably too thin to use. There is not more than 10 feet of siliceous shale about 30 feet below the railway track. It softens in water but does not slake. After grinding, it may be molded with 20 per cent of water and develops a tensile strength of over 50 pounds per square inch. Its air shrinkage is 3.5 per cent. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0.0	17
03	Salmon	0.0	16
01	Salmon	0.3	15
1	Red	0.5	6
3	Red	0.6	2

It becomes too hard to scratch with a knife at cone 03 (1994° F.), and viscosity is reached at cone 3 (2174° F.). The range, therefore, is 180°+. If abundant, this material might be used for hard burned products.

CLAY COUNTY

	1. Cretaceous	b) Silts of Red River Valley
Types of clay,	2. Pleistocene...........	a) Gray drift
		Shale

Dark blue Cretaceous shales were found at Fargo across the river m Clay County, at a depth of 220 feet, and are known to be over feet thick. No doubt they extend into Clay County.

At Moorhead several plants have been installed to make use of thin upper leached and oxidized portion of the silts of the Red River lley. Only 16 inches of clay here is of good quality. If the underg clay is mixed with this, much trouble is encountered in ying. It is necessary to work such a large area to obtain the y when it is so thin, that at most plants a few inches of soil have en stripped off from the clay to be used and spread upon the surce of the shallow pit from which the clay has already been removed. his allowed the continuous use of the soil for farming purposes, cept over the few acres which were being actively worked. The clay lakes in 1 minute, and its plasticity is low. It requires 22 per cent f water for molding. Its tensile strength is well above 100 pounds per quare inch, even when it is rapidly dried, and the air shrinkage is 5 per ent. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Buff	0	33
01	Buff	0	33
2	Buff	1	29
5	Buff	......	......

The clay becomes hard at cone 3, although satisfactory brick can be made at somewhat lower temperatures. Its temperature of fusion is rather higher than that of most of the clays which contain so much lime. It has a range of vitrification of nearly 200°. The several plants which have been operating in this neighborhood produced soft-mud brick and the capacity of each was rather limited. They are no longer operating.

At Barnesville, samples were taken from two points, one a mile east of town, and one about the same distance north at the site of an old brick yard. Both of these samples were taken so as to include several feet of the blue clay as well as the very thin layer of leached material on top. Scattered crystals of gypsum appear in one of the samples. The clays slake in 2 minutes, and are highly plastic, requiring 39 per cent of water for molding. When very carefully dried, the briquettes have a strength of over 100 pounds per square inch, but they crack to pieces unless dried with care. Furthermore, a test of the adhesive quality of pieces of wet clay pressed together shows that the use of an auger machine might result in very defective structure. The shrinkage on drying is 7 per cent. Both the clays burn buff at temperatures as high as 2000°

F. The sample taken from the east side of town shows a good range of vitrification and reaches viscosity at cone 4 (2210° F.). It should be capable of making even better and harder brick than formerly were made north of town.

CLEARWATER COUNTY

Pleistocene gray drift is the only clay reported in the county, and it needs cleansing before it is capable of successful use. Lakes are notably less abundant than in neighboring counties.

COOK COUNTY

Red clays are reported in considerable abundance and are apparently like the "water-laid moraine" so common around the shores of Lake Superior. The following analysis of a sample sent to the University of Minnesota in 1897, by Chester McKusick, is reported by Dr. C. P. Berkey.

Analysis of Red Clay from Cook County

Silica	53.39
Alumina	14.259
Iron oxide	13.706
Lime	3.033
Magnesia	1.740
Alkalies	not reported
Combined water	9.995
Carbon dioxide	4.278
	100.451

COTTONWOOD COUNTY

Types of clay,	3. Recent	Lake clay
	2. Pleistocene	Gray drift
	1. Cretaceous shale	

About half a mile from the station at Windom is a deposit of gray drift, which has been explored to a depth of 8 feet over a great many acres. In parts of the neighborhood it is undoubtedly of a greater thickness. The clay slakes in 3 minutes and is fairly plastic, requiring 24 per cent of water for molding. Its tensile strength is about 50 pounds per square inch, and the air shrinkage is 6 per cent. Burning tests by the Minnesota School of Mines Experiment Station are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
03	Salmon	1	20
01	Salmon	7	17
1	Brown	8	5
5	Brown	......	......

The clay burns hard at cone 03 (1994° F.), and is viscous at about cone 3 (2174° F.). An attempt was made to use this clay at the Windom Brick and Tile Factory, and the product is said to have been satisfactory.

A lake clay which has been used by the Bingham Lake Brick and Tile Company since 1904, occurs on the northeast side of Bingham Lake. It is known to be 9 feet thick over several acres. A few small limestone pebbles seem to have been washed into the upper layers of the clay, but the main part of the deposit is free from them. The clay slakes in 1 minute, and is highly plastic, requiring 32 per cent of water for molding. The tensile strength is over 125 pounds per square inch, but this is decreased somewhat by rapid drying. The air shrinkage is 7 per cent. Burning tests made by the Minnesota School of Mines Experiment Station are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	1	22
03	Red	2	20
02	Red	3	19
01	Brown	9	6
2	Brown	......	......

The clay becomes too hard to be scratched with a knife at about cone 03 (1994° F.), and reaches viscosity at cone 2 (2138° F.). The company have specialized in the manufacture of tile rather than brick, of which they can produce about 650,000 per year.

Cretaceous shales at depths of about 300 feet are found by drilling.

CROW WING COUNTY

Types of clay, Pleistocene..............b) Gray lake and river clay
a) Red drift

About a mile northeast of the town of Brainerd, a yard was started along the banks of the Mississippi River in 1876 to produce cream brick from laminated clays. The clay is exposed in the bluff and overlaid by about 20 feet of sand. Where the sand has protected it from weathering, it is uniformly gray in color, but work at this point has been abandoned, as most of the easily accessible clay has been used up and the removal of 20 feet of sand to obtain about 30 feet of clay did not appear to be profit-

able. The clay is of excellent quality, and either this or some neighboring deposit may yet be used, though between this locality and the town of Brainerd, no such clay seems to be available.

The clay slakes at once, and shows a fairly high plasticity, requiring 24 per cent of water for molding. Its air shrinkage is 4 per cent and its tensile strength well above 100 pounds per square inch even when rapidly dried. Burning tests by the Minnesota School of Mines Experiment Station are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
02	Buff	1	25
1	Buff	2	22
2	Buff	2	22
4	Buff	7	11

At cone 01 (2066° F.) the clay becomes too hard to be scratched with a knife, and it reaches viscosity at cone 4 (2210° F.).

In 1886, at about the time this clay along the river was abandoned, it was found that there was an outcrop of similar material a few hundred yards east where a tributary stream had eroded the overlying sand. A brick yard is now in operation upon this deposit and, though the upper portion has been leached to a yellow color, it is essentially similar in origin. It seems rather more sandy, however, and it burns to a red brick. It probably is available under about 200 acres of land. The clay slakes in 4 minutes, is highly plastic, and requires 24 per cent of water for molding. Its tensile strength is only about 50 pounds per square inch, and its air shrinkage is 8 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	16
03	Salmon	3	12
1	Red	6	3

The clay becomes hard at cone 05 (1922° F.), and viscous at cone 1 (2100° F.). The plant has machinery with a capacity of 20,000 brick per day, but works only half day shifts, producing sand-mold common brick.

DAKOTA COUNTY

Types of clay. 3. Recent.................. Alluvium
2. Pleistocene.............. b) Loess
a) Red and gray drift
1. Decorah shale

The Pleistocene and Recent clays are not important. A small brick yard at West St. Paul makes use of red burning leached drift. The clay may be made up of a sort of outwash. It slakes at once, and its plasticity is rather low, though it requires 28 per cent of water for molding. Its tensile strength is over 100 pounds per square inch, and the air shrinkage is less than 4 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	1	18
01	Red	2	16
1	Red	5	10
3	Red	7	8
5	Red	......	......

The clay becomes hard at cone 01 (2066° F.), and is nearly viscous at cone 5 (2246° F.). It should, therefore, be possible to burn it to a very excellent hard product. The plant which has been working this deposit is relatively small, and is now practically abandoned.

The most important formation is the Decorah shale, which is best developed along the Mississippi River bluffs at West St. Paul. The distribution of the Decorah shale in this county may be seen by reference to the State map. (See Plate I.)

In West St. Paul and Mendota the geologic section is as follows:

		Thickness
7.	Drift	65 feet
6.	Shale and limestone (many layers of limestone)	40 feet
5.	Hard limestone	3 feet
4.	Shale (½-inch lenses of limestone)..........	40 feet
3.	Limestone	18 inches
2.	Shale	3 feet
1.	Platteville limestone	12 feet

This is about the maximum thickness in the State. The lower part of of the large body of shale, number 4 of the section, seems to differ slightly in character from the higher shale beds which alternate with the limestone. Results of tests of samples of each horizon are as follows:

1. The lower shale is smooth and green in color, slakes in 2 minutes, and is very highly plastic. It requires 28 per cent of water for molding, has a tensile strength of nearly 100 pounds per square inch, and is unaffected by rapid drying. Its tensile strength is remarkable in that two pieces which have been cut apart and again pressed together, as by the auger machine, readily adhere with about as much strength as before. This eliminates most of the common defects of bricks made in Minnesota.

The air shrinkage of this clay is less than 6 per cent. If rapidly burned, there is a strong tendency to the formation of black cores with the consequent swelling and destruction of the brick, but if the organic matter is carefully oxidized in the early part of the process, the results are as follows:

Cone No.	Color	Shrinkage Per Cent	Per Cent Absorption
010	Salmon	4	13
06	Salmon	6	9
04	Red	......	......
02	Brown	......	......

The clay burned too hard to be scratched with a knife at cone 010 (1742° F.) and was not viscous at cone 02 (2030° F.), if burned very slowly to avoid black cores. In the laboratory tests an efflorescence appeared on the brick taken from the furnace which might indicate a tendency to the production of "kiln white."

2. The upper shale can usually be quite cleanly separated from the interbedded limestones and gives about the same results as the lower bed, except in the matter of color which is much lighter. A little less water is required to make it plastic. The clays yield the following analyses:

Table VI. Analyses of Decorah Shale at West St. Paul

	1	2
Silica	50.81	54.66
Alumina	20.25	24.04
Iron oxides	5.18	6.53
Titania	0.50	0.66
Lime	4.05	0.45
Magnesia	2.13	1.08
Soda	0.28	0.47
Potash	5.69	5.37
Moisture	2.16	2.35
Ignition	8.92	5.15
	99.97	100.76

1. Upper layers } F. F. Grout, Analyst.
2. Lower layers }

The plant of the Twin City Brick Company, one of the largest in the State, is located at the boundary line between West St. Paul and Mendota. Here this company has a very extensive quarry and produces brick and hollow ware, with a capacity of nearly 100,000 a day. Brick are burned to about 2100° F., varying considerably with the type of product desired. The main variations in the products are controlled (1) by the proportion of upper and lower shale used; (2) by the temperature used in burning; and (3) by the supply of fuel and air at the various stages of burning, resulting in oxidation and reduction. Work was begun in this neighborhood over 20 years ago and has progressed with many changes in method and control, and the final consolidation and

success have been largely due to the present management. Market conditions are of course excellent. Various details of manipulation have been patented and the ingenious devices which have been developed on the ground are worthy of careful study by any one planning to make use of Decorah shale. Although the shale burns red under normal and laboratory conditions, it is capable of being altered by the control of the fuel supply and by shutting off the supply of air so that the resulting brick are given various dark shades of color. Fancy brick, front brick, and klinker brick are produced in such quantities and bring such high prices that the production of common brick and drain tile has practically ceased at this plant. One of the many interesting special products is an interlocking tile for building block.

The following test of the products made in West St. Paul are available. Professor Talbot, of the University of Illinois, reports a crushing strength of 1,100 pounds per square inch, for hollow block about 4 x 4 x 13 inches, with the opening through the block in a horizontal position. Also a strength of 3,500 pounds per square inch for hollow block about 4 x 4 x 4 inches, with the opening through the block in a vertical direction. The City Building Inspector of Minneapolis, in testing the hollow block, found a crushing strength of 900 pounds per square inch as an average of ten tests on blocks 4½ inches square and 12½ inches long. The Building Inspector also tested some solid brick, finding an average of 3,300 pounds per square inch, with a minimum of 1,775 and a maximum of 6,250, in ten bricks tested.

DODGE COUNTY

Types of clay, 2. Pleistocene .... b) Gray lake clay
a) Gray drift
1. Decorah shale

In the eastern portion of the county, along the head waters of the various branches of the Zumbro River, the Decorah shale and the Galena limestone outcrop. The Decorah shale probably underlies most of the county and affords the most promising formation for the manufacture of clay products. Shales, without a very heavy overburden, outcrop in the vicinity of Mantorville and Kasson within a mile or two of the railroad. These should be investigated as a probable source of brick material. Gray drift, such as is being worked at West Concord for the manufacture of drain tile, covers most of the county. It contains numerous pebbles and is underlaid by sand.

At West Concord the pit exposes 8 feet of gray drift which extends over many acres. The pebbles are not quite as numerous as in the aver-

age gray drift, but were responsible for the failure of an attempt to make use of the clay. After fine grinding, the clay behaves as follows: It shows low plasticity, and requires 22 per cent of water for molding. Its air shrinkage is 5 per cent. Burning tests by the Minnesota School of Mines Experiment Station gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	15
01	Red	3	14
1	Red	5	8
3	Red	6	7
5	Brown	......	......

The clay becomes too hard to be scratched with a knife at cone 02 (2030° F.), and is still undeformed at cone 6 (2282° F.). It would seem that fine grinding and burning to a fairly high temperature would make it possible to use this clay with satisfactory results.

Gray laminated clays occur about 2 miles southwest of Hayfield on the Great Western Railway, in a deposit which is known to cover many acres to a depth of 30 feet. This has been exposed along the banks of the creek and most of it is blue and sandy, though weathered yellow near the top. There is practically no overburden along the creek, but it increases to 15 feet of soil and drift at a short distance away. A few small pebbles were observed, but they do not seem to be a serious disadvantage. The clay slakes in 4 minutes, shows fairly high plasticity, and requires 19 per cent of water for molding. Its shrinkage on drying is 4 per cent and its tensile strength is about 150 pounds per square inch even when it is rapidly dried. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	16
01	Salmon	2	13
2	Brown	6	5
4	Brown	......	......

The clay becomes hard at about cone 02 (2030° F.) and reaches viscosity at cone 4 (2210° F.) If market conditions are found favorable, this clay should supply material for a brick industry.

DOUGLAS COUNTY

Types of clay, 1. Recent...............................Lake clay
2. Pleistocene...........................Gray drift

At many points attempts have been made to work the gray drift to make common brick and, where the limestone pebbles are less

abundant than usual, some success has attended the effort. At Alexandria gray drift is very favorably situated with respect to market and shipping facilities. A sample of the drift taken at the intersection of the Great Northern and the Soo lines was very much like the material used at Hutchinson, but a trifle more sandy. This should not be a serious defect, since it is possible to discard some of the sand in the pit, and the clay vitrifies with the same range as that from Hutchinson. North of Alexandria, at the station of Miltona, a brick yard is in operation on a small scale, using a few feet of the leached upper part of a mass of gray drift from which the limestone pebbles are almost entirely gone. This leaching has apparently been effective over an area of several acres and there should be enough clay to keep a small plant in operation for several years. The air shrinkage of the clay alone is 11 per cent, but a larger proportion of sand is added in practice and the shrinkage thereby reduced, although most of the available sand contains a good deal of lime, and an excess is decidedly injurious.

At the northeast edge of the town of Alexandria, the McKay Brick Company for several years made brick from a bog deposit extending over 10 acres and known to extend to a depth of more than 5 feet, but the bog was so wet that only 5 feet have been used. Very few pebbles have been washed into this deposit. The clay is so rich that 10 or 15 per cent of sand is usually added. This is found at several convenient points throughout the neighborhood. The clay slakes in 2 minutes and is highly plastic, requiring 22 per cent of water for molding. The tensile strength is 175 pounds per square inch and is well above 100, even if the clay is dried without special precautions. The air shrinkage is 4 per cent. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	2	15
02	Salmon	3	12
1	Red	5	8
3	Red	6	6
5	Brown	......	......

The clay burns too hard to be scratched with a knife at cone 03 (1994° F.), and does not reach viscosity at cone 5 (2246° F.). It should burn to a very excellent hard vitrified product, though apparently it has been used only for a good grade of common brick. It is unfortunate that a disagreement among the owners caused the abandonment of the plant.

In the northwest corner of the county, laminated clays occur along the shores of Pelican Lake, and on the islands in the lake.

These may be partly of glacial origin, but as the outlet of the lake is now being eroded and the lake level is being lowered, recent deposits are being continuously exposed. Three or four feet of sandy soil overlies the clay, and some ferruginous concretions are visible in the clay itself. It slakes in 3 minutes and is very highly plastic, requiring 31 per cent of water for molding. The tensile strength is 190 pounds per square inch, though considerably less if the clay is rapidly dried. The drying shrinkage is 7 per cent. It burns to a good buff color and vitrifies at about cone 2 (2138° F.) This should be developed if there is any market for clay brick. Similar clay is said to occur on Abbots Point, on the south shore of Lake Miltona, not as well situated as that on Pelican Lake.

FARIBAULT COUNTY

Types of clay, Pleistocene...............b) Gray lake and river clays
a) Gray drift

Gray drift covers almost the entire county, but is too pebbly at most places to be of much economic importance. The fine, plastic, laminated clay has been used at Winnebago and Blue Earth for brick and tile. The only clay plant in operation in the county is located at Winnebago, although Blue Earth City supplies the raw clay which is used at the Fairmont plant where it is shipped.

The deposit at Blue Earth is known to extend to a depth of 20 feet over 10 acres and probably has much greater dimensions both vertically and areally. It is covered with only 2 or 3 feet of soil, and near the top has a layer in which there are many lime pebbles. The clay slakes in 2 minutes and is highly plastic, requiring 33 per cent of water for molding. Its tensile strength is less than 50 pounds per square inch in the average of 4 tests. Its air shrinkage is 8 per cent. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	3	23
03	Red	4	18
01	Red	5	16
2	Red	......	1

The clay burns hard at cone 04 (1958° F.), and is viscous at cone 2 (2138° F.) This clay is now being used by the Fairmont Drain Tile and Brick Company, located at Fairmont in Martin County. The capacity of the plant is 25,000 tile per day. The plant was erected at a cost of $150,000 with the expectation of making use of a local clay, at Fairmont, but this was found to be so full of limestone pebbles as

to be useless. The whole surrounding country has been prospected for a suitable clay and only two or three deposits were found available. The Blue Earth material is the only Minnesota clay now used, but some small amounts are imported from Mason City, Iowa. Hollow brick and tile are being produced.

At Winnebago, in Faribault County, along the Milwaukee tracks west of town, there is a deposit of about 70 acres of clay which is known to extend to a depth of 30 feet. It is covered with only 2 or 3 feet of soil. Limestone pebbles occur here and there in this deposit, especially near the top, but the Winnebago Drain Tile Company, which has a good plant making use of the clay, have a process of treating the clay with salt to counteract the effects of lime. This is said to work very satisfactorily. The details of the process, or the particular salt used, the company was not free to make public.

FILLMORE COUNTY

Types of clay, 4. Pleistocene ....Loess
3. Cretaceous clay
2. St. Lawrence, Galena, and Maquoketa, not important
1. Decorah shale

The Decorah shale occurs on terraces at an elevation of from 1,070 to 1,130 feet along the banks of the Root River and its several branches. It constitutes a persistent spring horizon. The distribution can be seen on the map, Fig. 12.

Preston, the county seat, has an abundance of these green shales, some of which are favorably situated for development. Chatfield is also well supplied with the shale. The average thickness of the Decorah shale in Fillmore County is only about 20 feet. A sample was taken in Elmira township. In working and burning, this proved to be essentially similar to the shale at West St. Paul, though there were some indications that rapid drying might be harmful. The range of vitrification is over 400° F. (Cone 010 to cone 2.) This shale is not used in the county and is recommended as the most valuable material available.

Although clays thought to be of Cretaceous age are known in Fillmore County, they have not yet been developed. Half a mile north of the village of Hamilton, along the road between Fillmore and Mower counties, is a clay which seems to be Cretaceous, but may possibly have been reworked by glacial action. It is red near the surface, but gray and carbonaceous below. Its thickness is nearly 20 feet, and it is estimated that it extends over 30 acres. The clay

slakes at once and is very highly plastic, requiring 45 per cen water for molding. Its air shrinkage is 11 per cent. It burns red color and becomes hard at a low temperature, not over 175(If rapidly heated, the organic matter causes swelling and black c(but if fully oxidized it can be heated to cone 2 (2138° F.) witl deformation. It should, therefore, be capable of producing good vitr ware.

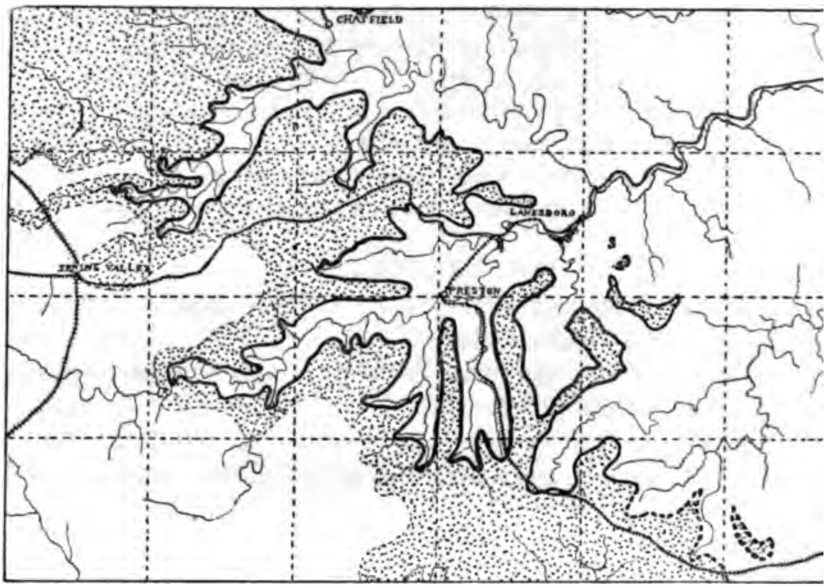


FIGURE 12. MAP OF FILLMORE COUNTY. DOTTED AREA UNDERLAID BY DECORAH SH

The loess covers the eastern two-thirds of the county, wher forms a mantle varying in thickness from 2 to 20 feet over Paleozoic formations. Its greatest thickness is seen at the bas(the slopes along the valley. On the high prairie land, although i not so thick, it is much more evenly distributed. Many abando yards have used it in the past. Such yards occur at Rushford, Peter: Whalen, Lanesboro, Fountain, Spring Valley, Carimona, Forestv Harmony, and Mabel. Material for red brick is still available at e of these places.

At Preston is one of the most important of the loess depos The section exposed is as follows:

Loess loam	6 inches
Yellow loess	10 feet
Bluish gray loess (to an unknown depth)	5 feet exposed

The yellow loess is the part of the deposit being used and the blue-gray material is reported as being too plastic for use in a sand-mold brick plant. The deposit is very extensive and will furnish material for good common red brick for many years. The plant is located about a mile north of town. The yellow clay slakes in 1 minute and shows a rather low plasticity. It requires 23 per cent of water for molding and its air shrinkage is 2½ per cent. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	2	18
03	Red	2	18
01	Red	4	15
1	Red	7	8
3	Red	9	2
5	Red	......	......

The clay becomes hard at cone 04 (1958° F.), and reaches viscosity at cone 4 (2210° F.). The U. S. Bureau of Standards reports it unsuited for auger machine molding; also that it is likely to crack in burning.

A sample of the underlying blue clay showed essentially the same properties, and, so far as indicated by laboratory tests, it could probably be worked into brick and burned to a satisfactory product. It was a little more porous as burned to the low temperature, and required a little higher temperature to make it hard. The plant here has a capacity of 30,000 brick per day and is steadily operated.

FREEBORN COUNTY

Types of clay, 2. Recent...........Swamp clay
1. Pleistocene........b) Gray lake and river clays
a) Gray drift

The glacial drift is too pebbly to be of much value.

Two clay plants only are worked in Freeborn County: one at Albert Lea, and one at Glenville, about 12 miles southeast of Albert Lea. An old abandoned plant exists at Conger. The material used at these places consists of laminated clays of a blue-gray or yellow color. Other deposits of this nature might be discovered at several places in this region.

Within a mile north of Glenville, the Acorn Brick and Tile Company have developed a deposit of laminated clay which occupies at least 10 acres and is known to be over 10 feet thick. Where exposed, the color is yellowish brown from oxidation. The overburden is

from 2 to 3 feet. The clay slakes at once, shows fairly high plasticity, and requires 30 per cent of water for molding. Its air shrinkage is nearly 8 per cent, and its tensile strength is very low, not over 25 pounds per square inch in the briquettes made. From the appearance of these briquettes, it is evident that flaws may develop upon drying, even when great care is used. The clay burns red and has a fair range of vitrification, reaching viscosity at cone 3 (2174° F.) The plant produces both red brick and drain tile, which are said to be of fair quality, though the plant was not operating at the time it was visited.

Two and a half miles southeast of Conger, in this county, is a deposit of 30 feet of laminated clay extending over nearly 100 acres, with the usual section beginning with 3 feet of black soil, and followed by 8 or 10 feet of yellowish clay, below which is the blue or gray clay. At the base of this section a gravelly bed occurs. In 1904, a company was organized to work this deposit, but shipping facilities were inadequate and the work ceased in about 4 years. Both the gray and the blue clay were used as dug from the pit, with the addition of some sand which had to be hauled from a distance. No tests were made to determine whether the blue and gray clays were similar.

The Albert Lea Brick and Tile Company have erected a plant just outside the city limits north of the town of Albert Lea, where there is a large hill of perhaps 25 acres, in which the formations are arranged as follows: an overburden of 2 or 3 feet of soil, 16 feet of yellow clay, 26 feet of blue clay. The clay is laminated and shows the usual irregularity of clays of this type. The blue clay is more plastic than the yellow, and slakes rather more promptly, but both are excellent in these respects. The blue clay shows a rather lower tensile strength, about 60 pounds per square inch, which is greatly injured on rapid drying, as the manufacturers have discovered at considerable cost. The yellow clay is much more satisfactory, having a tensile strength of over 100 pounds even when rapidly dried. A test for the adhesive properties of two wet pieces of clay after being pressed together and dried shows that it is not very great and there is an indication that the auger laminations would be serious. This also has been the experience of the company, and they have sought to use about 25 per cent of non-plastic material, such as cinders, burnt clay, or sand, to overcome this lamination. The drying shrinkage of the blue clay is 6 per cent and of the yellow, 3 per cent. Burning tests at the Minnesota School of Mines Experiment Station are as follows:

The Blue Clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	2	30
02	Salmon	4	26
2	Yellowish green	......	......

The Yellow Clay

05	Salmon	1	37
03	Buff	1	36
1	Buff	1	36
2	Greenish yellow	......	......

The clay burns to a fairly satisfactory product at these lower temperatures, but does not become very hard until nearly at the temperature of viscosity. The range of vitrification is approximately from cone 1 to cone 2. Tests of a mixture of the blue and yellow clays gave results similar to those obtained when the clays were burned separately.

The U. S. Bureau of Standards report[1] the following: An extremely fine-grained clay from Albert Lea, Minnesota, of considerable plasticity, but troublesome to dry. The specific gravity of the powdered dry clay is 2.58. Linear shrinkage in per cent of the wet length is 9.79. Mechanical analysis by elutriation gave:

Coarser than 120-mesh..........................	0.24
Average .577 mm. diameter.....................	0.21
Average .0354 mm. diameter....................	1.04
Average .0167 mm. diameter....................	0.96
Average .005 mm. diameter (and less)...........	97.31

The viscosity of the clay suspension was determined (water=1) to range from 1.1 when containing 7.5 per cent by weight of clay to 2.21 when containing 43 per cent by weight of clay, but the curve was not very straight. When the clay was heated to a temperature of 200° to 400° C., and cooled and worked up to the plastic state, it required less water than before to bring it to good molding consistency. The change was greatest (43 to 36) between 200° and 250°. After a treatment of this sort the volume shrinkage is much less than before and rapid drying causes no injury. The improvement in this clay at 350° is remarkable. Ninety-five per cent of the bricks were cracked before heating; none after. A proposed test[2] for plasticity using the absorption of a colored dye indicates a much great plasticity than in the others tested in this same study.

[1]Bleininger, A. V., Preheating clays: U. S. Bureau of Standards, Bull., Vol. 7, No. 2.
[2]Ashley, H. E., Colloid matter in clays: U. S. Geol. Survey, Bull. No. 388.

The following analysis was made by Mr. G. W. Walker, of the University of Minnesota, for Mr. M. R. Rusfeldt of the company.

Analysis of Gray Laminated Clay from Albert Lea

Silica	54.90
Alumina	13.94
Iron oxide	5.16
Lime	7.36
Magnesia	3.28
Potash	1.88
Soda	2.13
Titanium	0.84
Loss on ignition	12.54
	102.02

The bricks made of the gray laminated clay of Freeborn County have been tested by the Experimental Engineering Department of the University. The stiff-mud bricks had a crushing strength of 2463 pounds per square inch. The absorption was 25.8 per cent.

A deposit consisting of an extremely fine-grained silty clay, which is possibly in the nature of fullers' earth, occurs in a swamp in Secs. 11, 12, 13, and 14, T. 103 N., R. 20 W. The material could probably be used for common brick or drain tile. The following analyses are available, the first two of which were made by Mr. A. D. Meeds, and the last two by Dr. G. B. Frankforter, both of Minneapolis.

Analyses of Freeborn County Swamp Clay

Silica	55.52	57.60	59.37	57.62
Alumina	13.55	14.19	11.82	14.35
Iron oxides	3.99	2.89	6.27	2.50
Lime	8.00	7.00	6.17	8.11
Magnesia	3.16	3.51	2.09	2.98

The remaining 15 per cent is largely water and carbon dioxide, with traces of phosphoric acid, chlorine, and the alkali metals. Water constitutes nearly 13 per cent.

GOODHUE COUNTY

Types of clay, 4. Recent .... Alluvium
3. Pleistocene .... b) Loess
a) Gray drift
2. Cretaceous clay
1. Decorah shale

Goodhue County is noted for its good clays and its clay-working industries. The most important sources of clay are the Cretaceous.

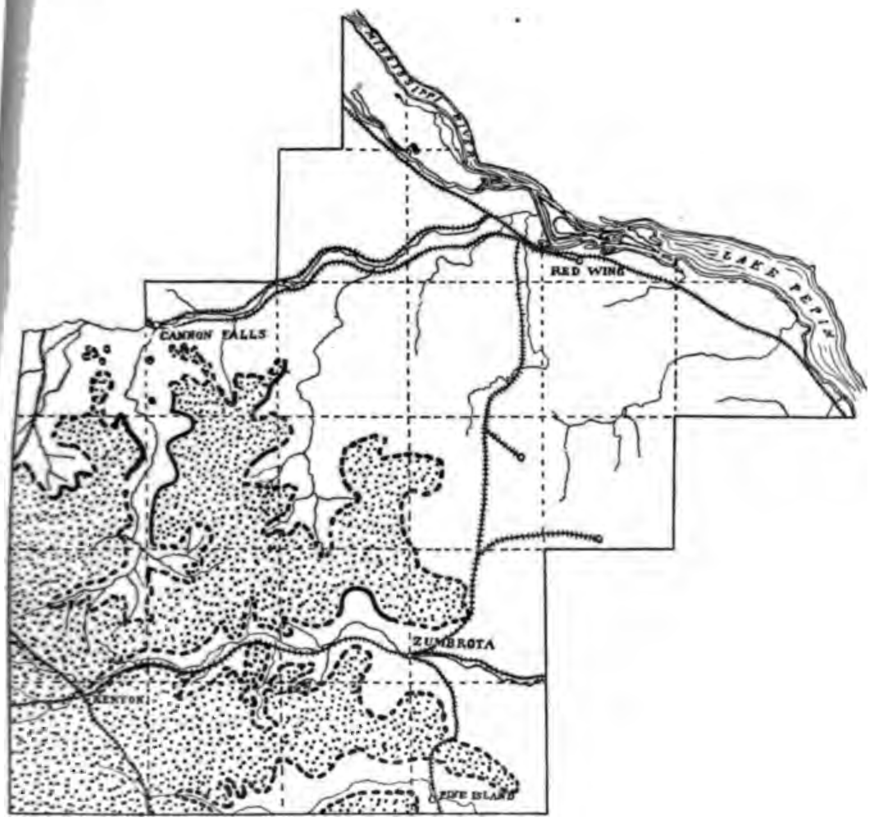


FIGURE 13. MAP OF GOODHUE COUNTY. DOTTED AREA UNDERLAID BY DECORAH SHALE. THE RAILROAD SPURS RUN TO THE CRETACEOUS CLAYS.

THE DECORAH SHALE

This has been carefully studied and mapped as shown in Figure 13. The geologic section and the physical character of the clay are almost identical with those at West St. Paul, Dakota County. The clay is being used at Zumbrota and Wanamingo, and a company is being organized to develop the shale at Cannon Falls. At Wanamingo the following geologic section was exposed:

Surface loam and loess	4 feet
Green shale	4 feet
Limestone	10 inches
Limey green shale	3 feet
Platteville limestone	14 feet
Hard limey shale	2 feet
Shale	3 feet
St. Peter sandstone	

At the Wanamingo plant the shale seems to require a few degrees higher temperature for vitrification. The clay at Wanamingo was tested by the U. S. Bureau of Standards and was found to be very similar to other Decorah samples, except that it had a somewhat greater tendency to crack in drying and form black cores in burning. The decrease in porosity with rise in temperature was slow, steady, and favorable to the production of vitrified brick. Although the deposit is relatively thin, the plant has a capacity of 120,000 brick per day. The plant is recently built, and the prospects are that it will be eminently successful.

In Minneola Township, the Zumbrota Clay Manufacturing Company is operating a plant using a rather massive bed of the shale some 15 feet thick, with slight variations in different parts. The clay was tested by the U. S. Bureau of Standards, which reports a uniform vitrification with increase of temperature, but the best temperature of burning is rather lower than for most good clays. The plant has a capacity of about 50,000 brick per day, but makes drain tile and hollow brick in addition to common brick.

Tests made by the Minneapolis Building Inspector of the hollow building blocks with two holes lengthwise, are as follows: The average of six blocks tested on the side and on the edge was 330 pounds per square inch, and one block tested on end gave 5,100 pounds per square inch.

At Cannon Falls the character of the clay as to behavior in the fire is almost identical with that at West St. Paul. The exposures in all of these localities extend from the St. Peter sandstone upward some 40 feet above the Platteville limestone, after which a mantle of glacial drift of varying thickness is found.

CRETACEOUS CLAYS

The stoneware and sewer pipe factories at Red Wing have become justly famous from their high-grade products and derive their most excellent clays from two occurrences a few miles south along the Great Western Railroad. The best known of these is at Clay

, about 13 miles south of Red Wing. According to F. W. son[1] this clay illustrates a remarkable case of transportation acial ice of a large mass of bed-rock formations. The clay ened in the pits is underlaid with gravelly drift and the stratifi- ı is greatly disturbed, crumpled, and irregular. (See Plate III, The usable clays are separated by layers of sand and sandy , and careful sorting has to be done during the process of min- For a long time several grades were shipped from the pit, some hich was used for sewer pipe and the rest for stoneware, but, ıe material has been found to be very limited, a plant for wash- the lower grade, darker colored clay has been installed to make for the higher priced stoneware. The complexity of the deposits re locally exposed is indicated in the following section:

Surface drift	1 to 3 feet
Gray clay	4 feet
Sand	1 foot
Clay	12 to 14 inches
Sand	8 inches
Gray clay	6 feet
Sand	10 inches
Clay	1 foot
Sand	2 feet
Clay	14 feet
Sand	1 foot
Clay	1 foot
White sand-bottom	10 feet+

PROPERTIES

The average clay slakes in 3 minutes, has a fairly high plasticity l requires 34 per cent of water for molding. It has a tensile ıngth of about 100 pounds per square inch, whether dried rapidly or . The shrinkage on drying is about 6 per cent. As burned by the U. Bureau of Standards, the clay has the following properties: The ɔr ranges from buff to gray during burning. The clay becomes d at about cone 010 (1742° F.), and softens at about cone (2786° F.). This is a remarkable range, but the porosity at no e was found to fall below 6 per cent in the best grade of clay. e temperature recommended for burning is about cone 5 (2246° F.). e second grade of clay from the same pit, which is usually washed

[1]Sardeson, F. W., The so-called Cretaceous of southeastern Minnesota: Jour. Geol., . 6, p. 679.

before using in the stoneware plant, behaves very much the same; but without washing, it burns to a lower porosity and has nearly an equal range of vitrification. The third grade of clay, used only for sewer pipe, is much like the latter. As burned at the University the clay is found to become hard at cone 010 (1742° F.), and reaches viscosity at about cone 10 (2426° F.). It is cream-colored or buff at higher temperatures. Analyses are reported in Table II, page 45.

At Belvedere, half a mile east of Belle Chester, a new deposit of Cretaceous clay recently has been developed, and its success may be taken as an indication that still other deposits of such excellent clay may yet be brought to light. This deposit was discovered by careful prospecting and observation of fragments in the drift followed by careful drilling before any excavation was undertaken. It will average 10 feet in thickness, ranging from 1 to 25 feet over an area of 40 acres. Its appearance is similar to that at Clay Bank and its origin is assumed to be the same. The deposit is capped by 3 to 6 inches of ferruginous sandstone, and below it is a similar sand rock apparently of Cretaceous age, though its crumpled condition would indicate transportation by glacial ice. This is the deposit now used by the Red Wing Sewer Pipe Company, though a part of it is of sufficiently high grade to be selected for the stoneware factory. The Red Wing Sewer Pipe Company has two plants at Red Wing and one at Hopkins, near Minneapolis. (See Plate VII.) In addition to the production of sewer pipe they manufacture a few vitrified drain tile and other specialties. Their capacity is 35,000 car loads per year.

Tests by the U. S. Bureau of Standards are as follows: The best clay at Belle Chester is satisfactory in plasticity and molding properties and requires 21 per cent of water for molding. It shrinks 7 per cent on drying and does not crack. The color of the burned clay is buff at low temperatures and gray at higher ones. The porosity decreased from 29 per cent at cone 010 to 20 per cent at cone 02 and 10 per cent at cone 5. It softens at cone 20, and is therefore not highly refractory.

Second-grade material from the same pit as tested by the Bureau of Standards showed much the same behavior, but softened at cone 18 and, when burned at medium temperatures, showed a green efflorescence.

While these two localities are the only ones of commercial value now known, traces of the clay are seen at numerous places in the drift in the form of fragments, streaks, pockets, and thin lenses. "Ironstone" fragments similar to the ferruginous shale layers associated with the clays at Clay Bank and Belle Chester, are also frequently found in the drift. These indications of clay seem to be most

numerous northwestward from the deposits now being worked. There are strong possibilities that systematic prospecting with drills or augers will result in the discovery of other isolated areas of Cretaceous clay in the eastern part of the county.

RED WING STONEWARE TECHNOLOGY

The clay is mined by hand digging in benches and vertical sided rectangular pits. It is loaded directly on to the cars for shipment to Red Wing, or to Minneapolis. The factory at Red Wing has produced stoneware since 1872. This plant now uses 75 tons of clay per day. Clays for glazing are obtained from the southern states, but it is possible some suitable slip clay may be found in this State.

Clay from the pit is shipped by rail to the plant where it is unloaded into bins. Several grades of clay are recognized, some of which are so pure as to require no preliminary treatment, but the bulk of the clay for the manufacture of stoneware is first subjected to a washing process to remove sand and other impurities. This clay is all reduced to a slush in blunger mills and passed through rotary sieves or lawns (80-mesh) and then run into large settling vats or cisterns. Live steam is used in the blunger mills and throughout the washing process, and the slush is kept almost to the boiling point to facilitate the washing and pressing. The coarser sand and impurities are removed in the rotary sieves or sifters. The slush is then pumped into large filter presses where the water is strained out and the clay is pressed into the form of cakes weighing about 40 pounds each. The filter cakes go to the mill room and are tempered in pug mills. The clay is then loaded on small trucks and distributed around to the various benches in the plant ready for the skilled workmen to mold. The molded pieces go to tunnel dryers where they are kept for 36 hours, and the moisture removed. When the ware comes from the dryer, it is finished and glazed and is then ready for the kilns. The ware is burned at a temperature of about 2200° F., and the heat is maintained from 45 to 60 hours, depending upon the product desired. It requires nine days from the first process of preparation until the product is finished.

The quality of the ware made at Red Wing is excellent. As compared with the stoneware and sewer pipe produced in other localities, it is found that the temperature of fusion is rather lower than the average, but the range of vitrification (over 700°) is so great that the product is not at all to be condemned on account of the low temperature of burning. Its vitrification and strength may be fully equal to that burned at higher temperatures.

OTHER CLAYS

A deposit of gray drift has been explored by the Red Wing Sewer Pipe Company near the village of Goodhue in Sec. 10, in the hope that it will be available as a plastic bond for mixing with the Cretaceous sewer-pipe clay. The deposit is 20 feet thick and covers 80 acres. It is dark brown to yellowish in color and is covered with 4 feet of sand and soil. Although it is to be classified as glacial drift, it is remarkably free from pebbles, and may be composed of debris from Cretaceous deposits over which the ice passed. The clay slakes in 1 minute, is very highly plastic, and requires 26 per cent of water for molding. The tensile strength is well above 50 pounds per square inch, but the brick is considerably weakened by rapid drying. It would have a good effect in increasing the strength of a non-plastic sewer-pipe clay. Its air shrinkage is 9 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
07	Red	3	8
05	Red	4	10
1	Red	7	4
2	Red	8	......
5	Red	......	13

The clay burns hard at cone 07 (1850° F.), and becomes viscous at about cone 8 (2354° F.). Having thus a range of vitrification of 500 degrees, it may be safely used for vitrified ware, such as sewer pipe, for which it is recommended. Some preliminary experiments by the Sewer Pipe Company have resulted rather unfavorably. Possibly the mixture of the two clays may not behave as well as would be indicated by either one alone, but the U. S. Bureau of Standards reports very favorably on a mixture of ⅔ Cretaceous sandy clay and ⅓ this clay.

Cone No.	Color	Porosity
011	Pink	24
05	Buff	17
02	Buff	15
2	Gray	10

The mixture would be better for making sewer pipe than either clay alone.

At the town of Pine Island the loess is exposed to a depth of 5 or 10 feet over a very large territory. The deposit was worked up to about 6 years ago, and produced a fair quality of red brick, but there is not much local demand for the product.

Two miles from Vasa is a sandy alluvial clay along Belle Creek, rather favorably exposed, but apparently too sandy to make a good grade of brick. A few kilns were burned about 50 years ago, and

the brick seem to have stood the test of service, but the sample taken was so sandy and weak that it could hardly have been possible to pile the brick into a kiln. This may not have been representative material.

At Frontenac, also in this county, John Bartron has a deposit of alluvium along Wells Creek a considerable distance from the railroad. It is known to be over 4 feet thick. An analysis made for Mr. Bartron by F. F. Grout, is as follows:

Analysis of Clay at Frontenac

Silica	63.32
Alumina	12.68
Iron oxides	2.66
Lime	5.08
Magnesia	3.94
Moisture	1.83
Ignition	8.47
Alkalies, etc., by difference	3.02

Sand-lime brick are manufactured at Red Wing. The lime is shipped in from Iowa and the sand is taken from a hill of modified glacial drift near the factory.

GRANT COUNTY

Types of clay,	2. Recent	Lake clays
	1. Pleistocene	Gray drift

Gray drift covers most of the county and an attempt made to use it at Elbow Lake was not very successful. Along the shores of Pelican Lake are clays of another type which may be worthy of development.

HENNEPIN COUNTY

Types of clay,	3. Recent	Alluvium
	2. Pleistocene	b) Lake and river clays
		a) Red and gray drift
	1. Decorah shale	

At Minneapolis the glacial river clays have been developed on the north side of the city, for cream brick, pottery, and fire-proofing, for which there is still an abundant supply, but the value of city property tends to crowd brick works northward into Anoka County. Detailed

discussion of the clay is given with those of Anoka County. The pebbly gray drift of the county, and recent alluvium along the Mississippi River, cannot well be used in competition with this deposit. The red drift is in most places deeply buried. Swamp clay was used at Hanover and gray drift was once used at Rogers, but the operations were not successful. The Decorah shale is mostly eroded, partly buried, and occurs in property more valuable for city lots than for development of clay. The excellent qualities of the glacial clay used are shown by large industries developed here and in Anoka County, just to the north.

Mention should be made of the sand-lime brick factories at Minneapolis.

HOUSTON COUNTY

Types of clay, 3. Pleistocene loess
2. Decorah shale
1. St. Lawrence formation

The shales of the St. Lawrence formation outcrop in many bluffs, but have no value at the present time.

The Decorah shale occurs in the extreme southwestern corner of the county. It can best be developed in the vicinity of Spring Grove where good outcrops were seen, but proved to be rather thin. A mantle of loess covers most of the county.

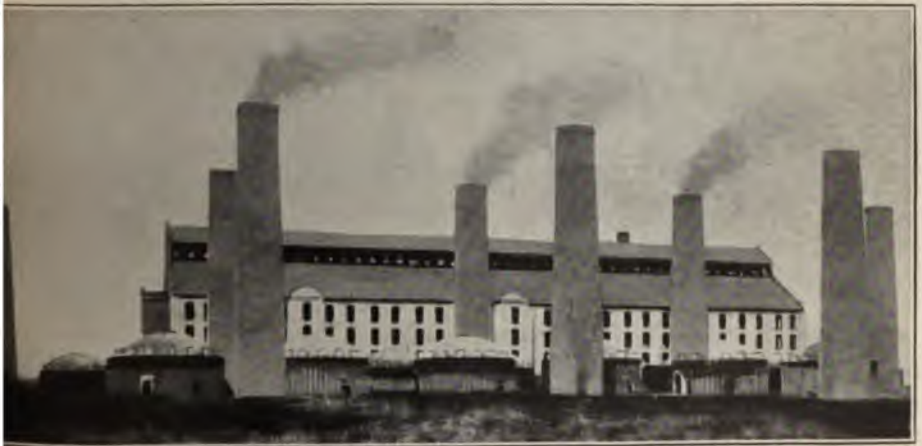
There were no brick yards in operation in the county in 1912, but old plants were located in former years at nearly every town in the county,—Money Creek, Spring Grove, La Crescent, Houston, and at other localities. Common red brick can be made from the loess at nearly any locality in the county.

HUBBARD COUNTY

Types of clay, 2. Recent .... Lake clay
1. Pleistocene .... Gray drift

Near Akeley, a mile and a half from the Great Northern Railroad, a plant has been operating on a deposit evidently formed in the bed of a lake which may be at least partially of glacial age. The deposit is known over an area of 80 acres and at places is 40 feet thick. The upper half of the deposit is yellow and the lower half blue-gray, but both parts burn to cream-colored brick except a few inches at the top from which the lime has been leached. At the plant the production is about 200,000 stiff-mud cream-colored brick per year.

A. FACTORY "A"—RED WING SEWER PIPE CO.



B. THE MINNEAPOLIS SEWER PIPE WORKS. A MODERN FIRE-PROOF FACTORY.

Gray drift was used a few miles from Park Rapids, but the plant not been active since 1894. The clay is said to be fairly free from estone, and work was stopped because the market was small and funds were not sufficient to tide the company over ill times.

ISANTI COUNTY

ıes of clay, Pleistocene ....b) Gray lake and river clay
a) Gray drift

At Cambridge and elsewhere along the Rum River, gray laminated was used for many years, beginning in 1881. The clay is now ɔsed for 20 feet, but is overlaid in the bluff with about 25 feet of l. It could be profitably worked for only a small area where overlying sand has been at least partially eroded. The clay slakes ıce and shows fairly high plasticity, requiring 29 per cent of water molding, and shrinking 7 per cent on drying. The clay becomes at cone 04 (1958° F.), at which temperature it is salmon-colored, vs a shrinkage of 2 per cent and an absorption of 23 per cent. It hes viscosity at cone 2 (2138° F.). A local plant manufactured ıon brick from this laminated clay, but the work has been aban-ed. A high proportion of sand was used in tempering, and was ined from the overlying bed. The addition of 50 per cent of this l raised the temperature of vitrification slightly, but did not ıge the general character of the product.

One or two attempts were made to use the gray drift, but they met usual difficulty.

ITASCA COUNTY

es of clay, 4. Recent...........Lake clays
3. Pleistocene........c) Lake and river clays
b) Gray drift
a) Red drift
2. Cretaceous
1. Huronian.........Paint rock, etc.

No clays were worked in this county up to 1900. Since then the elopment and activity on the iron ranges have led to the use of e clays in the southern part of the county—the glacial lake or r clays at Verna and Grand Rapids. The deposit near Verna is the e promising. The Verna Brick Company has opened a deposit of lami-ed clay near the station of Warba on the Great Northern Railroad. deposit which is considered available is about 10 feet thick, and

extends over about 10 acres. It is yellow in color, and apparently has been leached. Underlying it and extending over a great many acres of the surrounding country is a blue laminated clay with a few limestone pebbles, which in some well records is reported to be more than 60 feet thick. The yellow clay burns to a cream-colored product, while the blue clay is said to burn red and show a much greater shrinkage. Any attempt to mix the blue and yellow clays meets the usual difficulty in mixing a stiff, plastic clay with a lean, more sandy one. The plastic lumps remain suspended in the more fluid mass and a great amount of pugging or some other form of mixing is necessary, if one would avoid a defective structure resulting from auger laminations. The yellow clay which is being used slakes at once, and shows very low plasticity, requiring 23 per cent of water for molding. The air shrinkage is 3 per cent and the tensile strength is well above 100 pounds per square inch even after rapid drying. Burning tests gave the following:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
03	Buff	1	30
01	Buff	4	23
3	Greenish buff	......	......

The clay becomes hard at cone 02 (2030° F.) and reaches viscosity at cone 3 (2174° F.). The plant which is operating at this point has a capacity of 35,000 brick per day and makes a common brick of cream color. Wood is the most available fuel.

At Grand Rapids bricks were burned from a very sandy laminated clay, which was discovered along the banks of the stream at the northeast edge of town. This clay is yellow in color, and seems to be very sandy when dry. It slakes in 1 minute, and its plasticity is very low. It requires 21 per cent of water for molding and has a shrinkage of 3 per cent on drying. The tensile strength is over 130 pounds per square inch, but the adhesion test indicates that it would not work well in the auger machine. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	1	21
03	Brown	4	13
1	Brown	5	10
3	Brown	......	......

The clay burns too hard to be scratched by a knife at cone 02 (2030° F.), and becomes viscous at cone 5 (2246° F.). In two attempts at brick making soft-mud machines were used and in another, a stiff-mud machine.

None has been particularly successful, and work has ceased. Shipping conditions are not very favorable.

Cretaceous shales have been reported[1] to outcrop along Deer River, River erosion had cleaned off these deposits and left them with smooth polished surfaces, which are more resistant to erosion than the glacial drift. It was generally assumed that the limey concretions were rare occurrences in the Cretaceous. In the present investigation, a somewhat hasty examination revealed no outcrops except those containing a considerable number of lime concretions or pebbles. On the Big Fork River, two miles below the mouth of Deer River, blue clay outcrops near water level. It is sticky and tough but is not readily accessible and it is so near the water level that it would not be profitable. Similar outcrops occur on the Big Fork River 2 miles above the mouth of Deer River.

Half a mile above the mouth of Deer River, which is about half way to the first dam on Deer River, 4 to 6 feet of clay is exposed for 50 feet along the bank. It probably is connected with another outcrop close to the mouth of the river. The clay is laminated with alternately light and dark blue layers. It is covered with about 10 feet of glacial drift and contains a few rounded pebbles. This deposit is rather more accessible than the last two mentioned, and it appears to be the best clay discovered in this region. Its plasticity is high and 34 per cent of water is needed in molding. The shrinkage on drying is about 9 per cent. Tested by the Minnesota School of Mines Experiment Station, it showed the following properties:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	......	15.0
2	Salmon	......	0.5

The clay was undeformed and too hard to scratch with a knife, at both these temperatures. It has a good range of vitrification. Slow heat is needed to avoid black cores.

The mantle of gray drift over the county is largely modified and sandy, but the surface of it is irregular and small lakes abound. Clays have accumulated in these lake basins, probably beginning in glacial times, but continuing to the present. The character of this type of deposit is indicated by the clay at Lilly Lake south of Grand Rapids. Numerous test pits and borings have revealed deposits of clay and irregularly interbedded sand, which seem to be of excellent quality for common brick. The clay slakes in 3 minutes, shows fairly high

[1]Grant, U. S., Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 4, p. 183.

plasticity, requiring 28 per cent of water for molding. Its air shrinkage is 7 per cent and it checks considerably even when carefully dried, so that its tensile strength is usually less than 50 pounds per square inch. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	2	17
04	Salmon	4	15
01	Red	8	8
1	Red	9	3
2	Red	9	2

The clay becomes hard at cone 05 (1922° F.), and reaches viscosity at cone 2 (2138° F.).

At Coleraine, the paint rock of the iron-ore formation is especially troublesome in the mines and is over 20 feet thick. It is all moved in getting the ore and, if a little care were used to keep it free from ore and the sandier layers of taconite, it is capable of being used for red brick, though not safely for a hard vitrified product.

At Pengilly, a particularly sandy phase of modified drift occurs over a large area and a sand-lime brick plant just erected has every chance of being successful if the necessary precautions are used to keep the product up to the high grade possible.

JACKSON COUNTY

Types of clay, 2. Recent...........b) Lake clay
a) Alluvium
1. Pleistocene........Gray drift

Brick and tile are manufactured from gray drift at the town of Jackson where a yellow clay with very little limestone or other impurities extends over 14 acres and has a depth of 15 feet. The deposit is close to the Milwaukee Railroad and conditions seem to be favorable for the development of a considerable industry. This is the plant which has developed the dry process of separation of limestone from the clay. The pit is carefully kept dry, and the clay is plowed over a considerable surface and gathered up only after the wind and sun have dried it pretty thoroughly. It is then transferred to sheds for further drying, with protection from rain. The crushing is done in a modified dry pan from which an elevator carries the clay to a screen. The limited space in the shed room greatly limits the capacity.

At Okabena, a similar deposit has been explored and two small plants for making hand-molded brick were built to make use of it. This clay has the common qualities and defects of the gray drift.

At Jackson, along the flood plain of the river, there is a deposit of clay of about 20 acres in extent, known to be 5 feet thick. It was developed about six years ago, and the product was used in several buildings in Jackson. Its working and burning properties seem to be excellent, but there are a few limestone pebbles which have caused difficulties. Blue clay is said to lie below it.

At Heron Lake, along a gentle slope on the northwest shore of the lake, there is a yellow laminated clay, probably partly of glacial origin, but also in part post-glacial. The deposit covers about 100 acres and has a thickness of 12 feet. The laminae are of variable thickness and many of the vertical joints are stained with iron. Except along the lake, the deposit is surrounded by pebbly gray drift.

A. V. Bleininger[1] reports the following tests: A glacial calcareous clay from Heron Lake possesses good plasticity and working properties, though it is somewhat too fine-grained for drying when made into larger pieces.

Specific gravity powdered dry clay = 2.654.
Linear shrinkage in per cent wet length = 7.72.
Mechanical analysis by elutriation gave:

	Raw clay	After heating to 300°
Coarser than 120-mesh	1.72	9.51
Average .577 mm. in diameter	0.98	3.29
Average .0354 mm. in diameter	8.03	5.57
Average .0167 mm. in diameter	9.03	4.44
Average .005 mm. in diameter	80.24	77.17

After a heat treatment of from 250° to 400° C., the plasticity is found to be lower, and the air shrinkage is greatly decreased. The decrease is greater, the higher the temperature of preheating.

Our sample evidently was not improved by preheating, for the raw clay showed no more cracking than the preheated clay, and was as good as the other clays studied after preheating. The effect of preheating on fineness of grain explains some of the variation found in plasticity and shrinkage.

An enterprising company operating at Heron Lake produce hollow brick and tile. They have been at work since 1890, and make use of a number of down-draft kilns with a capacity of about 80,000 brick per day. The product is cream-colored if burned hard, but salmon at lower temperatures. They find that the deposit is best suited for the manufacture of hollow brick and tile. The fusion is so sudden that the products are seldom vitrified.

[1]Bleininger, A. V., Preheating clays: U. S. Bureau of Standards, Vol. 7, No. 2.

KANABEC COUNTY

Types of clay, 2. Pleistocene........b) Gray lake and river clays
a) Red drift
1. Algonkian (?)....Red clastic series

At Mora, an attempt was made to use the shale of the red clastic series for terra cotta. Wells show a considerable extent of the shale below the drift, but it is rarely over 10 feet thick. It is exposed in Sec. 1, T. 39 N., R. 24 W. for about 100 yards along the river where it is about 3 feet thick. The clay slakes in 2 minutes, and is very plastic, requiring 22 per cent of water for molding. Its air shrinkage is 5 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Fire Shrinkage	Per Cent Absorption
06	Red	0	17
2	Red	2	14
5	Red	2	......
12	......	......	Melted

It becomes hard at cone 06 (1886° F.) and was undeformed at cone 5 (2246° F.). The range of vitrification is over 360° F.

An attempt was made to use the ferruginous shaley sandstone near by, but, as now exposed, it contains very little clay and it does not bond at all.

Yellow laminated clays outcrop in the bank of the river at the northwest side of the town of Mora. The deposit apparently extends over many acres and was sampled to a depth of 6 feet with an auger which did not reach the bottom. It appears to have rather numerous concretions of a limey nature, and the working qualities of the sample are not good. Its shrinkage on drying was over 13 per cent, and upon burning it checked and showed still further shrinkage. It can hardly be recommended for any purpose.

At several other points in Kanabec County, attempts have been made to manufacture brick from glacial clays some of which are the laminated lake clays. One plant was installed east of Rice Creek on the road from Brunswick to Grasston. The clay includes some sandy layers as much as 6 inches thick. It slakes at once, and is fairly plastic. It has an air shrinkage of 8 per cent, becomes hard at cone 05 (1922° F.), and reaches viscosity at cone 2 (2138° F.). If this deposit was favorably situated as to the market, it might be profitably worked.

KANDIYOHI COUNTY

Types of clay, Pleistocene........b) Gray lake clay
a) Gray drift

The laminated clays will form the chief clay resources of Kandiyohi 'ounty, though gray drift is abundant. A little over a mile west of Villmar, along the Great Northern Railroad, is a deposit of lami-ated clay known to extend over about 25 acres. It consists of yellow cidized material for 15 feet, under which is at least as much blue ay. In the yellow clay are a few limestone pebbles or concretions. he blue clay is as usual more plastic than the yellow and shows 'eater shrinkage when used alone. Both the yellow and the blue ay will burn to a cream color at high temperatures, but are salmon-lored if under-burned. The Willmar Brick Company has been at work :re for 20 years, making about 2 million stiff-mud cream brick each :ar. On the northwest side of Nest Lake another plant made use a similar clay.

The county contains many lakes and marshes and many of these ay be underlaid by alluvial clays.

KITTSON COUNTY

This county is no doubt supplied with such clay as is used at Grand Forks and at Winnipeg—the silts of the Red River Valley. Vells report it 136 feet deep and it is no doubt usable to as great a epth as at Grand Forks.

KOOCHICHING COUNTY

'ypes of clay, 2. Recent...........Alluvium
1. Pleistocene........c) Silts of Red River Valley
b) Gray drift
a) Gray lake clay

In the neighborhood of International Falls, the level character of he country is probably due to the erosive action of the waves of the ;lacial Lake Agassiz. Much of the surface consists of a sticky clay vhich has been reported to a depth of 40 feet. The upper portion s leached and relatively free from pebbles, but at a depth of 6 feet, imestone pebbles become rather numerous. The clay slakes in 2 ninutes and shows a very high plasticity, requiring 29 per cent of vater for molding. The air shrinkage is 9 per cent, and there is robably a considerable tendency to crack on drying, even if this is lone slowly and with care, for the tensile strength is below 50 ounds. Burning tests gave results similar to those which character-ze the gray drift, and it would seem that some method must be ap-plied to remove the coarser gravel before the clay can be safely used. The proportion of such gravel, however, is very much less than in

the common gray drift so successfully used at Hutchinson, but it is doubtful if that process will apply with equal success to the clay near International Falls. The success of the Hutchinson process depends, not only upon the removal of limestone, but upon the quality and the mixing of the materials that remain. The gray drift contains approximately 30 per cent of sand which would be caught in a 100-mesh sieve, but this clay in the Lake Agassiz basin shows only about 3 per cent of sand. Deposits of sand are not abundant anywhere in the neighborhood, and it is suggested that those who wish to make use of this clay should experiment with a grinding process rather than with the washing process recommended for pebbly clays elsewhere.

International Falls and the towns near by are developing so rapidly that special efforts should be made to find good clay. One promising sample was sent to the University several years ago from a point 5 miles east of Ranier, in Secs. 34 and 35, T. 71 N., R. 23 W. The sample made excellent bricks and is said to represent a body of clay 9 feet thick and 40 acres in extent.

At Big Falls, southwest of International Falls, the Big Fork River has cut an extensive gorge below the falls which give the town its name. The bluffs for most of the distance reveal a very pebbly blue clay weathered yellow near the surface. A little below the mouth of Sturgeon River, however, on the farm of Mr. Ben. Lind, is an outcrop of different material. It may be one which was mapped by U. S. Grant[1] as a Cretaceous deposit. The section is as follows:

Soil	1 foot
Common pebbly clay of the Lake Agassiz basin	10 feet
Plastic yellowish gray clay	10 feet
Very fine sandy clay	30 feet

This material outcrops for several hundred yards along the bluff and therefore represents a large deposit, though it is somewhat inaccessible in the present state of development of the country. The clay slakes at once, shows a medium plasticity, and requires 28 per cent of water for molding. Its tensile strength is over 150 pounds per square inch, even when it is rapidly dried, and its air shrinkage is 3.5 per cent. The clay burns to a buff-colored brick with a range of vitrification of about 100° F. and reaches viscosity at cone 4 (2210° F.). A sample of the rich clay without the underlying sandy clay showed similar properties, but vitrified at slightly lower temperature.

[1]Grant, U. S., Final Rep. Minnesota Geol. and Nat. Hist. Survey, Vol. 4, p. 183.

In this county several other patches of shale are noted by U. S. Grant.[1] These have now been visited and sampled to determine their quality. At present they are somewhat inaccessible. In Sec. 1, T. 64 N., R. 24 W., in the southwest bank of Little Fork River between two creeks which join the river from the south, are a series of small landslides. The banks of the river have slipped down to the water's edge, exposing a nearly white, smooth clay. This was sampled for a thickness of 15 feet. It could be traced continuously for several hundred paces, and is exposed here and there for several miles. The clay is slightly laminated with alternating layers of white and a light blue gray and has no visible impurities. It slakes in 1 minute, has a fairly high plasticity, and requires 23 per cent of water for molding. Its tensile strength is over 150 pounds per square inch and it is equally strong if rapidly dried. Its shrinkage on drying is less than 4 per cent. Burning tests by the Minnesota School of Mines Experiment Station are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Buff	0	23
03	......	2	20
01	Buff	3	20
2	Buff	3	20
5	Buff	......	......

The clay becomes hard at cone 03 (1994° F.) and is just reaching viscosity at cone 5 (2246° F.). A few miles down the river in Sec. 15, T. 65 N., R. 24 W., just below Seller's Rapids, similar clay outcrops near water level and was sampled at a point where the river water had washed over it recently. The physical properties of the clay were very much the same as those of the sample just described, except that the air shrinkage was 8 per cent and the color was red at low temperatures and brown above cone 2. Vitrification occurred at slightly lower temperature, from cone 06 to cone 3, a range of about 300° F. These are the best clays in the county.

At Big Falls, a small creek bed passing the west edge of town has cut into irregular layers of sand and clay which overlie the usual pebbly drift of the region. The deposit may be partly leached drift and partly alluvium. If this is as extensive along the creek as it seems to be, it should furnish a local brick supply. The clay slakes in 1 minute, is highly plastic, and requires 20 per cent of water for molding. Its tensile strength is well above 200 pounds per square inch, even when rapidly dried. Its air shrinkage is 4.5 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
01	Salmon	1	17
2	Chocolate	......	......
4	Chocolate	......	......

The clay becomes hard at cone 01 and is viscous at cone 4. The range of vitrification is, therefore, over 150° and it can safely be burned hard.

All these clays have the properties of glacial rather than Cretaceous deposits.

LAC QUI PARLE COUNTY

Types of clay, 3. Pleistocene ....Gray drift
2. Cretaceous ....Shale
1. Archean ....Residual clay

Gray drift, somewhat modified near the surface, covers the county, and the Cretaceous shales and Archean clays are found only in wells. At Dawson and southwest, white clay of the appearance of the Archean is met at a depth of 160 feet.

LAKE COUNTY

Types of clay are the red drift and associated lake clays. They have not been used. Possibly some swamps contain clay. The Keweenawan rocks show thin shale lenses, probably of no value.

LE SUEUR COUNTY

Types of clay, 3. Recent ....Alluvium and swamp clay
2. Pleistocene ....Gray drift
1. Cretaceous ....Shale

Near the town of Ottawa are several clay deposits. Half a mile below the railroad bridge over Cherry Creek, is an outcrop of clay lying between the Jordan sandstone and the Shakopee dolomite. It is only 2 or 3 feet thick where exposed, and there is considerable evidence that it is not in a comformable series with the Jordan and the Shakopee, but has been washed in during Cretaceous or pre-Cretaceous times. This is the first sample taken of a type which is widely distributed throughout the Minnesota Valley from Shakopee to New Ulm. The clays are variegated, red, yellow, and white, and occur here and there like stratified sediments unconformably above the Jordan or the Shakopee. Another common occurrence is in large

water-worn cavities and fissures. Before the deposition of these Cretaceous clays, the rocks of the Minnesota Valley had been channeled by rivers and other erosive agents into irregular basins, potholes, and hollows from 5 to 25 feet in depth, often partly covered by overhanging walls. These pocket-like cavities are smoothly water-worn. N. H. Winchell has described[1] an instructive section of the Shakopee dolomite and its associated deposits of this clay in a cut near the railroad bridge which crosses the Blue Earth River about a mile above its mouth. He says:

This cut is perhaps 70 feet above the river, the bank of which is composed entirely of rock, the lower portion of which is the Jordan sandstone, and the upper the Shakopee limestone, the latter composing about 20 feet. In general this railroad cut shows a mixture of Cretaceous clay with the Cambrian, the top of the whole being thinly and irregularly covered over and chinked up with coarse drift. The Cambrian is more or less broken and tilted, at least the bedding seems to have been cut out into huge blocks by divisional planes, which, either by weathering or water-wearing, were widened, the blocks themselves being subsequently thrown to some extent from their horizontality, tipping in all directions. The opened cracks and seams were then filled with the Cretaceous clay, which is deposited between these loosened masses, and sometimes even to the depth of 20 feet below the general surface of the top of the rock. The clay sometimes occupies nooks and rounded angles, sometimes sheltered *below* heavy masses of the Cambrian beds. The clay is uniformly bedded, about horizontally, with some slope in accordance with the surface on which the sedimentation took place. But the most interesting and important feature is *the condition of these old Cambrian surfaces.* They are rounded by the action of water, evidently waves. The cavities and porous spots are more deeply eroded, making little pits on the face of the rock; or along the lines of section of the sedimentation planes with the eroded surface, there are furrows due to the greater effect of water. The rounded surface of these huge masses of limestone is coated with a thickness of about a half inch, or an inch and a half, of iron ore, which scales off easily, and is easily broken by the hammer. While this scale of iron ore is thicker near the top and on the upper surface of the blocks, yet it runs down between the Cretaceous clay and the body of the rock.

The sample collected at Ottawa slakes in 2 minutes, is very highly plastic, and requires 31 per cent of water for molding. Its tensile strength is over 100 pounds per square inch even when dried rapidly. Its shrinkage on drying is 8 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Red	4	14
04	Red	7	11
02	Red	9	7
1	Red	10	3
6	Red	......	......

The clay becomes hard below cone 07 (1850° F.) and viscous at cone 10 (2426° F.). Analyses are reported in Table III, page 45. Its qualities are thus shown to be so excellent that it may be worth while to search out more deposits of this character to ascertain whether some of them may not warrant development.

[1]Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, Second Annual Report, p. 178.

Another clay deposit near Ottawa was developed a little over half a mile up Cherry Creek and half a mile from the Northwestern Railroad. Mr. Randall, on whose farm the clay occurs, reports that it was tested for 27 feet without reaching the bottom. It underlies an area of the high prairie east of Ottawa where rocks are not exposed. The geologic section reported by Mr. Randall is as follows:

Yellow clay drift	0-100 feet
White clay	4 feet
Blue clay	8 feet
White clay	4 feet
Fine white sandy clay	Bottom

This clay outcrops in the bed of the creek and there might be some difficulty with the drainage. It slakes in 1 minute, is very highly plastic, requiring 26 per cent of water for molding. It shrinks 4 per cent on drying. Burning tests by the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Cream	4	20
02	Cream	5	20
2	Cream	8	14
4	Cream	8	14
13	Gray	......	......

The clay is notably hard at cone 05 (1922° F.), fully steel hard at a slightly higher temperature, and apparently is not even approaching viscosity at cone 13. The Bureau of Standards reported it as behaving like a refractory clay. It may prove to be highly refractory, but it appears to burn dense at moderate temperatures. The following is the average of five analyses made for the company.

Silica	58.70
Alumina	28.50
Iron oxides	0.18
Magnesia	0.23
Lime	0.69

The St. Paul Fire Brick Company was organized to exploit this deposit and a plant was constructed with a capacity of several million brick per year. No products have been turned out for several years. Probably further work would be successful.

As a third type of clay at Ottawa, the river bluffs, half a mile

m the depot of the Omaha Railroad, expose from 50 to 100 feet gray drift for a considerable distance. A few feet of coarse avelly drift overlies the bowlder clay which was sampled. ıe clay slakes in 3 minutes and its plasticity is low. It requires per cent of water for molding and has an air shrinkage of 3 per nt. Its tensile strength is nearly 200 pounds per square inch, though it ecks slightly if rapidly dried. Owing to the presence of abundant par- les of limestone the product falls to pieces if burned to temperatures low cone 2 (2138° F.). The limestone is so abundant that the ay melts at a temperature a few degrees higher. To make use of is material, it would be necessary to apply some process for re- oving the limestone pebbles, but as it occurs in the same neigh- rhood as some apparently high-grade Cretaceous clays, it was ought worth while to call attention to it. A plant making use of ıe of these clays might easily increase the variety of its product ithout greatly increasing the expense of an installation.

The gray drift in other parts of the county is not as good as the her clays available. An attempt was made to use it for brick at 'aterville, but some swamp clays near by are more promising.

At Le Sueur, the alluvium of the Minnesota River is favorably posed along the Omaha Railroad. Similar deposits are found at ankato, and here and there along the Minnesota River. The sample ken slakes at once, has a fairly high plasticity, and requires 28 per nt of water for molding. Its air shrinkage is 6 per cent, and its nsile strength about 50 pounds per square inch. Burning tests gave e following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
03	Salmon	0	26
01	Brown	3	20
1	Brown	4	18
2	Brown	7	11
3	Brown	......	2

'he clay becomes hard at cone 01 (2066° F.), and reaches viscosity t cone 3 (2174° F.). Soft-mud brick can be produced at the rate f about 10,000 per day. The brick are red in color, and have stood the st of service since 1882 in some of the buildings in Le Sueur.

LINCOLN COUNTY

Gray drift covers the whole area of the county. No deposits were ound to be well situated for development. Cretaceous shales are known rom well records only.

LYON COUNTY

Types of clay, 3. Pleistocene ....Gray drift
2. Cretaceous ....Shales
1. Archean ....Residuals

The gray drift covers the county, but, owing to its lime content, attempts to use it have failed. At Marshall, where shipping facilities are good, it might be possible to clean the clay. Cretaceous clays within 50 feet of the surface have been discovered by well drilling.

The Archean lies too deep for exploitation.

McLEOD COUNTY

The only clays known in McLeod County are of the gray drift, although some recent lake clays may be present.

The only brick yard in the county is located at Hutchinson, where an excellent quality of brick and drain tile are manufactured from the ordinary gray drift. The glacial drift there is similar to that found over large sections of the State. It contains numerous lime and quartz pebbles, some sand and gravel, and a few large bowlders. The plant here successfully used this material, where many others have failed, because of the special washing process devised by Mr. M. C. Madsen, by which the pebbles and sand and other impurities are completely separated from the clay. This process is of especial importance to those who may be interested in the ceramic industry because it opens a field for the utilization of a vast amount of material which has heretofore been considered valueless. A description of this plant and the methods used is given on page 25.

The upper part of the gray drift at Hutchinson is weathered yellow. (See Fig. 2.) Blue-gray clay of equal value lies at depths greater than 16 feet. The extent of the deposit is to be measured in scores of square miles, and the over-burden at many places is but a few inches of soil. The clay slakes in 5 minutes, is fairly plastic, and requires 24 per cent of water for molding. Its tensile strength is nearly 100 pounds per square inch and over 75 pounds when it is rapidly dried. The following analysis is in the records of the company, and was made on washed material.

Analysis of Washed Gray Drift, Hutchinson

Silica	48.25
Alumina and iron oxides	36.60
Magnesium carbonate	0.70
Calcium carbonate	1.49
Alkalies	4.46
Loss on ignition	8.50
	99.00

A second analysis stated below was furnished by Mr. M. C. Madsen, manager of the company, to Professor Ries, of Cornell University.

Silica	60.31
Alumina	23.77
Ferric oxide	7.96
Lime	2.50
Magnesia	1.75
Alkalies	242
Water	...
	98.71

These two analyses, though varying widely, probably represent only a difference in the thoroughness of washing, and both clays seem to be capable of yielding a high-grade product. The washed clay, burned by the Minnesota School of Mines Experiment Station, gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	......	......
05	Salmon	1	24
03	Salmon	2	23
1	Yellow	7	9
3	Yellow	8	8

The clay burns too hard to be scratched with a knife at cone 06 (1886° F.) and becomes viscous at cone 3 (2174° F.), thus having a range of about 300°. It can be safely burned to a very hard product. Tests made on common brick by the Experimental Engineering Department of the University of Minnesota show an average crushing strength of 2,834 pounds per square inch. The particular advantage of the drain tile here produced is that they resist frost exceedingly well. To obtain further details of its physical character, the clay as used at the plant was

washed through a series of sieves. The proportion of sand to clay as determined by what passed the 20-mesh sieve and what passed the 100-mesh sieve, was 30 to 70. It is thought that closely similar gray drift wherever found to contain about 30 per cent of sand, would be suitable for the application of the Hutchinson process of treatment. Samples were taken from about a dozen widely separated places, and in most of those from which the washed clay showed 30 per cent of sand or a close approach to 30 per cent, the mixture of sand and clay burned to a product almost identical with that from Hutchinson. It is therefore safe to say that throughout at least half the State this material is available for the production of high-class brick and tile at a commercial profit unless some purer clay is available in the same region.

MAHNOMEN COUNTY

Pleistocene gray drift covers the county except where recent swamp deposits occur. These latter may prove to be worth investigation, but are not as numerous as in counties near by.

MARSHALL COUNTY

The silts of the Red River Valley overlie the gray drift in much of this county. North of Warren, the clay along the river has been used for many years. It is known to extend over 100 acres and the following section is characteristic:

Black soil	6 inches to 1 foot
Yellowish to brown pebbly alluvial clay	10 feet to 15 feet
Yellowish to gray stratified sand with pebbles	10 feet
Hard, blue, plastic, smooth clay	Depth unknown

The first 4 feet are almost free from pebbles and are used for soft-mud, cream-colored brick when there is a demand. The underlying blue clay was tested at the plant and is reported useless for common brick.

MARTIN COUNTY

Companies with capital invested have sought and offered prizes for the discovery of good clay here, without success. A fine silty clay of doubtful origin, suitable only for hand molding, is found at Granada. Surface loam was used for brick on the south side of Buffalo Lake, but they were not of good quality. The remainder of the

county is covered with gray drift, and this is usable only if the lime pebbles can be economically removed.

MEEKER COUNTY

Types of clay, Pleistocene ....b) Gray lake or river
a) Gray drift

Near Litchfield and Kingston, brick yards operated for years on some laminated clays apparently formed in basins in the ice. Limey concretions occur in certain layers. The gray drift north and west of Litchfield consists largely of clay, but is somewhat pebbly. South of Watkins, the gray drift is very widespread, but would require the usual cleansing treatment before successful use could be made of it. An attempt to use the clay without these precautions failed.

MILLELACS COUNTY

Types of clay, 2. Recent.................Lake and swamp clay
1. Pleistocene..............b) Gray lake and river clay
a) Red drift

At the station of Brickton, just north of Princeton, a group of brick factories producing about 15,000,000 brick per season are at work upon a deposit of typical laminated clay. Under the soil there is a superficial layer of clay rarely over 4 feet thick which has lost its laminated structure and apparently has been leached of its lime content so that it burns red. Below this there is 10 feet of yellow clay, followed by 10 feet of gray clay. All of these varieties of clay are usually worked together, mixed in the same proportion in which they are found. Below the gray clay which is being worked, is a considerable thickness of a rich joint clay, which is reported as having a greasy character, but has too much of a tendency to crack on drying to be satisfactorily used. Wells drilled through this find a water supply in gravel and sand which lies just below the joint clay. As is usual in such deposits, the sand occurs in pockets or irregular streaks throughout the deposit. In some pits all of the clay owned by the company may be better adapted for soft-mud brick than for the stiff-mud product which is easily made by the other companies. The main product is manufactured with stiff-mud machines and some small proportion is made light by a central opening for use as fireproofing. Considerable difficulty is found in auger laminations which weaken the product if the clay is not well mixed. Tests by the U. S. Bureau of Standards showed the following characters: The plasticity

is high and the auger machine does not produce serious lamination. The air shrinkage is 6 per cent after 26 per cent of water is used for molding. It retains a high porosity until vitrification begins, and it then fuses suddenly. The burned color is buff to greenish yellow at higher temperatures. The average bricks produced have a crushing strength of over 2,000 pounds per square inch as tested in the Experimental Engineering Department of the University.

The surface clay at Brickton, where weathered and leached, is reported as shrinking 8 per cent on drying, but it fuses about as suddenly as the main mass of clay. It has a good red color when burned.

Nearly all the remainder of the county is covered with gravelly red drift. An attempt was made to manufacture brick from it, at the station of Waukon, on the Soo Line. Here the drift contains fully the average amount of sand and gravel and no attempt was made to remove them or even to crush them very fine. The product made in the one kiln burned was naturally of rather low quality. After the clay is crushed to pass a 40-mesh sieve, it has the following characters. Plasticity is fairly high and the water required for molding is 20 per cent. The air shrinkage is about 5 per cent and the tensile strength about 100 pounds per square inch.

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	1	14.0
03	Red	3	10.0
1	Red	6	4.5
2	Red	......	4.0

Clay becomes hard at cone 04 (1958° F.) and reaches viscosity at cone 2 (2138° F.).

In the midst of large areas of red drift in the northern part of the county there are numerous swamps, some of which spread over 40 acres or more. In a few places there are exposures of clay of variable thickness along drainage ditches depending upon the depth of water in the original lake. A sample taken from the west side of Waukon slakes at once and shows a high plasticity, requiring 20 per cent of water for molding. Its tensile strength is about 100 pounds per square inch even when it is rapidly dried and its air shrinkage is 5 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	0	15.0
04	Red	1	14.0
02	Red	4	9.0
1	Red	6	1.5

The clay becomes hard at cone 05 (1922° F.) and reaches viscosity at cone 1 (2100° F.). This is evidently a type of the lake and swamp clays of the region of the red drift. Most of them would be capable of making a thoroughly hard, satisfactory brick.

MORRISON COUNTY

Types of clay,	3. Pleistocene	b) Gray laminated clay
		a) Red drift
	2. Cretaceous	Shale and conglomerate
	1. Huronian..................	Residual clay

Two or three miles west of Little Falls, Pike Creek has eroded a channel through a deposit of laminated clay which is being utilized at two yards for cream-colored brick. The upper 6 feet of clay has a yellow color, and there is an unknown depth of gray clay below it. As is commonly the case, the gray clay is much more plastic than the yellow and is here called joint clay. Thin layers of the joint clay alternate with the yellow in its lower part and about 2 feet of the unweathered joint clay can be mixed with the 6 feet of yellow clay without causing too much danger of checking. The clay slakes in 3 minutes, is highly plastic, and requires 24 per cent of water for molding. The air shrinkage is 5 per cent and the tensile strength is about 150 pounds per square inch, even when the clay is rapidly dried. Burning tests at the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
01	Cream	1.0	30
2	Yellow	2.5	25
3	Yellow	3.0	25
5	Yellow	......	......

The clay becomes too hard to be scratched with a knife at cone 01 (2066° F.) and reaches viscosity at cone 4 (2210° F.). It has been used for nearly 30 years, mostly for soft-mud cream-colored brick, though stiff-mud machinery has been made use of in recent years. Each plant has a capacity of about 40,000 brick per day.

At Bowlus, in this county, the main Two River has cut a channel into laminated clay which appears almost identical with that at Little Falls. The tensile strength of this clay is, however, somewhat injured if dried rapidly. The range of vitrification is less than that at Little Falls, the clay reaching viscosity at cone 1 (2100° F.). The Bowlus Brick and Tile Company was organized two years ago to work

this deposit, and is equipped to manufacture about 40,000 soft-mud cream brick per day.

Along the Mississippi River, near Little Falls, there are extensive outcrops of staurolitic biotite schist which yields residual clays. As noted by Winchell,[1] a trap dyke of basic dolerite, about 10 feet wide, crosses the slate diagonally. Clays probably of preglacial age are found on the south side of the dyke where they seem to have been protected from the erosion of water and possibly from that of glacial ice.

A few miles south of Little Falls at the Soo Railway bridge, a similar layer of decomposed mica schist has been exposed and at this point there seems to be no harder rock to serve as protection, but the decomposition is general and the resulting clay is very extensive under the drift. It may be followed 100 yards along the river and is visible on both sides. Auger borings showed it to be over 6 feet thick, becoming only slightly harder at that depth. It is probably many feet to solid rock. The clay still contains a large amount of partly decomposed mica, but decomposition has gone so far that the clay is waxy and plastic and can easily be molded. Still farther south near the mouth of the Little Two River, the same sort of material is exposed at the abutment of the bridge on the wagon road crossing the Little Two River. This material once caused great agitation and considerable prospecting for silver on account of the included silvery mica scales. The further extent of similar material is indicated in a report of Warren Upham.[2] At the mouth of the main Two River a well was sunk through 25 feet of decomposed schist and bored [illegible] farther into the same. All the lumps of rock thrown out crumbled to powder within a few weeks after exposure to the weather. The dry clay slakes at once and requires 33 per cent of water for molding. It shrinks 5 per cent on drying. It burns red, but remains soft up to cone 6 (2282° F.) and is past viscosity at cone 12 ([illegible]° F.). It can hardly be considered satisfactory for vitrification, but is more refractory than the common drift and recent clays.

In the banks of the Mississippi River, 2 miles east of Bowlus at the road bridge on the road from Bowlus to Royalton, near the clay just described is an outcrop of white clay. This is a bed about [illegible] feet thick which dips slightly to the south where it is overlain by Cretaceous shales. A few hundred yards north of the outcrop where one might expect the same clay to occur higher in the bank it [illegible] evidently been eroded and the Cretaceous remains only [illegible]

[1] [illegible], N. H. Minnesota Geol. and Nat. Hist. Survey, Final Rep. [illegible]
[2] [illegible], Warren. Minnesota Geol. and Nat. Hist. Survey, Final Rep. [illegible]

near the mouth of the Little Two River. In the outcrop near the bridge, the texture varies from massive white clay to a highly concretionary, very ferruginous red clay. The two extremes were separately sampled, but were found to behave very similarly. They do not slake when placed in water nor do they develop much plasticity even after grinding. They stand the temperature of cone 13 (2534° F.) without the slightest deformation and without becoming hard, though the ferruginous sample is the harder. They are evidently quite refractory. No use is being made at present of the deposits in this neighborhood. Professor Dodge[1] analyzed the concretionary material and the results which follow give evidence of the presence of bauxite.

Analysis of Concretionary Clay of Morrison County

Silica	19.81
Alumina	52.43
Iron oxides	1.32
Magnesia	1.64
Soda	0.44
Ignition	23.23
	98.87

Just south of the clay described is a shale containing Cretaceous fossils and including a thin layer of lignite. This shale was sampled at a point a few rods above the mouth of Two River near the road bridge over the Mississippi River. It is exposed for a thickness of 10 feet or more and can be traced more than 200 yards along the banks near water level. It is gray and waxy and apparently contains numerous small mica scales. Where exposed, it has very little overburden, but if traced for any distance it would undoubtedly be found to be covered with glacial drift. It dips a few degrees toward the south and is underlaid by the white basal Cretaceous clay just described. The clay slakes in 2 minutes and is not very plastic. It requires 26 per cent of water for molding and shrinks less than 4 per cent on drying. At cone 4 (2210° F.) it is salmon-colored and has just become hard. It reaches viscosity at about cone 10 (2426° F.). This should be of proper quality to serve as a plastic bond for the nonplastic fire clay, which occurs in the vicinity.

[1]Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, Final Rep., Vol. 2, p. 602.

MOWER COUNTY

Types of clay, 3. Pleistocene ....b) Loess
a) Gray dri
2. Cretaceous ....Shale
1. Devonian ....Shale

At Austin clays that are possibly of Cretaceous age overlie tl eroded edges of the Devonian rocks. A quarter of a mile nort west of the depot of the Milwaukee Railroad the Minnesota Fan ers' Brick and Tile Company has opened a deposit which varies fro 1 to 20 feet in thickness and underlies a large part of a property co sisting of 93 acres. Although the clay is described as Cretaceous, is somewhat modified and disturbed apparently by glacial actic and it is questioned by Sardeson[1] whether it ever was Cretaceoı The color of the clay is variegated and it contains a few pebbles aı rocks, especially where most disturbed near the surface. Glacial dr overlies it but is only a few feet thick. The irregular surface (which it rests is composed of sandstone and dolomite with a thin u per layer of blue clay rarely over 6 inches thick. The clay slakes 3 minutes and has a very high plasticity, requiring 31 per cent (water for molding. It shrinks 7 per cent on drying, and has a tensi strength of about 80 pounds per square inch even when rapidly drie Burning tests by the U. S. Bureau of Standards resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Porosity
013	Salmon	High	25.0
010	Salmon	High	20.0
08	Salmon	High	9.0
06	Red	High	1.0
03	Red	High	.6

There was a little trouble with checking, but it was not serious. Tł porosity was low over a considerable range of temperature.

The factory which has a capacity of 60,000 brick per day has be experimenting with different materials available to determine wheth or not high-grade products can be produced. Their work has yield excellent results. The clay commonly burns red, but by mixing some of the underlying Devonian rock, they have found it possib to produce buff- and cream-colored ware of equally high grade. Tl Devonian rock alone burns to a lime rather than a clay produ The 6-inch layer of blue clay between the bed rock and the Cretaceoı has also been burned, but the deposit is too small to be of value. does not differ greatly from the main body of clay.

[1]Sardeson, F. W., So-called Cretaceous of southeastern Minnesota: Jour. Geolog Vol. 6, p. 679.

At the northwest corner of the property owned by this company, a clay which seems to be of most excellent quality has been developed by drilling but has not yet been opened. It is at least 20 feet thick and is known to exist over several acres. It is somewhat stratified, and, though it contains some fine grit, it is highly plastic. Only 2 or 3 feet of soil lie above it and no impurities were discovered except a 6-inch layer of sand. The clay slakes in 5 minutes, but requires only 15 per cent of water for molding. It has a tensile strength of over 100 pounds per square inch, and its air shrinkage is less than 4 per cent. Burning tests by the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Buff	0.3	10
1	Buff	1.0	9
3	Buff	1.0	9
5	Buff	......	......
13	Gray	......	......

The clay becomes too hard to be scratched with a knife at cone 05 (1922° F.) and is undeformed at cone 13 (2534° F.). It may prove to be highly refractory, but as it burns dense at moderate temperatures, it is more suitable for stoneware or retorts than for fire brick. Probably such Cretaceous deposits may be found elsewhere in the neighborhood by detailed prospecting with augers and drills. An outcrop near Frankford is probably Cretaceous.

The gray drift covers nearly all of Mower County except along the bottoms of the stream valleys. At many places where it is free from gravel and other coarse impurities, it may be utilized for common red brick. The loess is here unimportant. Abandoned brick yards were noted near Frankford, High Forest, and Leroy, where common brick were made from the glacial drift and the loess.

Limey shale and shaley limestone of Devonian age are found at several localities in Mower County, notably near Frankford along Deer Creek and near Leroy along the upper Iowa River in the eastern part of the county. That at Austin is mentioned above. It contains 15 per cent magnesia and 20 per cent lime. Probably none of these limey shales are of value for brick or other clay products since they are non-plastic, sandy, and impure.

MURRAY COUNTY

This county has only gray drift of the usual pebbly type. It has been tested and found identical in its behavior with that used at Hutchinson.

NICOLLET COUNTY

Types of clay	1. Recent	...........Alluvium
	2. Pleistocene	...........Gray drift
	3. Cretaceous	..........Shale

In Nicollet County opposite Mankato, brick are manufactured from clay which seems to be essentially similar to that on the Mankato side in Blue Earth County. The clay is not continuous over the whole of the river flat, but occurs in patches surrounded by more sandy or gravelly deposits. The plant has a capacity of over 2 million brick per season. Similar clay is found at Judson, several miles up the river on the Nicollet County side.

At St. Peter, where the Northwestern Railroad crosses the Minnesota River, alluvial clay occupies a considerable area. This has the usual appearance and is apparently of the same quality as that found at Le Sueur. It was used [illegible] years ago for brick to build the asylum at St. Peter, and a similar deposit was developed just across the river at Kasota. Both plants are now closed. The clay slakes at once, and its plasticity is low. Its tensile strength is [illegible] pounds per square inch and its air shrinkage 4 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
02	Salmon	[illegible]	25
01	Gray	[illegible]	20
1	Brown	[illegible]	15
2	Brown	[illegible]	[illegible]

The clay becomes hard at cone 01 ([illegible]° F.) and reaches viscosity at cone 3 (2174° F.).

Several outcrops of Cretaceous shale are shown on the map[1] of Nicollet County. These are very close to the town of New Ulm, and are apparently similar to those in Brown County. In Sec. 34, T. 11[illegible] N., R. 30 W., at Mr. John Heinmann's lime kiln, is an outcrop about 10 feet thick which can be traced by poorer exposures for several hundred yards along the creek. This is a bedded shale underlying glacial drift and containing some small layers of limestone. It [illegible] is variegated. It is quite easily accessible. The clay slake[illegible] to lumps in 10 minutes. It is highly plastic and requires 23 pe[illegible] of water for molding. Its air shrinkage is 7 per cent and it[illegible] strength is over 100 pounds per square inch, but is somewhat les[illegible] clay is rapidly dried. Burning tests by the Minnesota School o[illegible] Experiment Station are as follows:

[1] [illegible], Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 3[illegible]

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0	14
03	Salmon	1	13
2	Red	......	......

The clay becomes hard at cone 05 (1922° F.) and is still undeformed at cone 2 (2138° F.), if the heating is not too rapid. Organic matter is apparently responsible for the formation of black cores with great swelling and deformation unless time is given for thorough oxidation. Outcrops of similar clays are found here and there for several miles along the north side of the river.

NOBLES COUNTY

The clay found in this county is the gray drift of the usual type. Brick and tile were made at Worthington 20 years ago, but the drift is somewhat pebbly and the clay is not found to be very satisfactory. If market conditions favored it, a plant of the type working at Hutchinson or Jackson might be successfully operated.

NORMAN COUNTY

Half a mile from the town of Ada is a deposit of the laminated clay of Red River Valley. The deposit has been proved over an area of 5 acres and is apparently much more extensive. It is known for a depth of 15 feet by borings which did not reach the botton. It is overlaid by only a few inches of soil. The clay is yellow and weathered for a depth of about 10 feet, and there is one 6-inch sandy layer included in it. Nearly all the brick buildings in Ada were made from these brick and have stood service very well. The plant has not been operated since 1906. The usual differences are observed between the blue and yellow clays, the former being more plastic and requiring more water for molding. The blue clay at this point requires 52 per cent of water for molding and shows a shrinkage of 17 per cent on drying. This water requirement and shrinkage are very large. It is almost impossible to avoid serious cracking during the drying process. It has the further defect of containing so much organic matter as to form black cores and considerable swelling even if heated with great care. The yellow upper part of the deposit is apparently best used without much addition of the blue clay underneath. It shows a fair range of vitrification, reaching viscosity at about cone 3 (2174° F.).

OLMSTED COUNTY

Types of clay, 4. Recent ....b) Swamp and lake clays
a) Alluvium
3. Pleistocene ....b) Loess
a) Gray drift
2. Galena ....Shale
1. Decorah ....Shale

Red brick have been made from the glacial clays in a number of localities. Nearly every town of any size in the county has a deposit of clay from which a fair quality of common brick could be made. The most important clay formation in the county is the Decorah shale. This has never been utilized, but in the future it is to this formation that attention should be given rather than to the in-

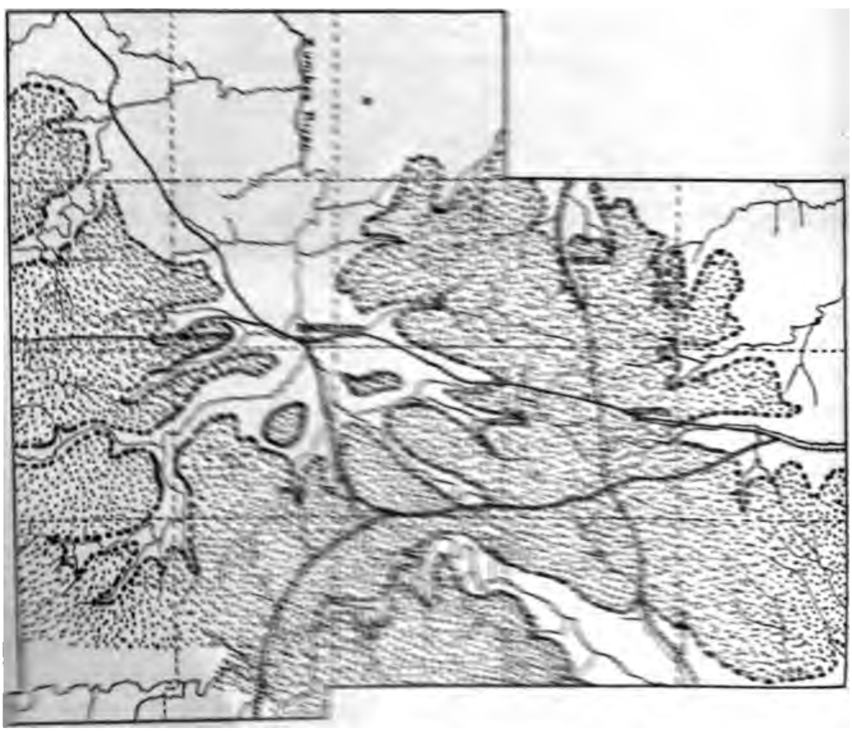


FIGURE 24. MAP OF OLMSTED [illegible] SHALE

[illegible] deposits of glacial [illegible] there [illegible] with loess. The [illegible] the [illegible] shown in the [illegible] The elevation

the shale above sea level is from 1,125 to 1,200 feet. The most favor-e localities for the development of this formation for the manufacture ceramic products are in the vicinity of Rochester and Byron. In southern part of the county, along the north branch of Root 'er, the shale outcrops on both sides of the stream, but is of small :kness and is inaccessible at present. Where the overlying lime-nes are missing, and where the shale is covered by glacial drift y, its presence is not easily detected, but if the neighboring out-)s give no sign of the removal of the shale, it is supposed to be sent under the drift. Around the city of Rochester, where a thin er of the Decorah shale forms a capping on many of the hills, it overed by only a few feet of drift and soil, and is therefore readily essible.

Two and one half miles north of the town of Byron on the terson farm, the Decorah shale is about 50 feet thick and covers ıy acres. (See Fig. 4.) Tests on a sample indicate the quality of the le in other parts of the county. Its plasticity is very high. It requires per cent of water for molding, and has a shrinkage of 11 per cent drying. In burning there is the usual tendency to form a black e and destroy the brick if the heating is too rapid, but a temper-:e of cone 02 (2030° F.) can be reached in a slow furnace without loss of the product. The range of vitrification is as great as in ıples of this shale from other places.

At Rochester there is a considerable deposit of alluvium along the ıbro River. This is known over 40 acres to a depth of 5 feet or re and it is supposed that its content of clay is derived at least part from the neighboring Decorah shale. It occurs in patches, rnating with sandy and gravelly material, as in most alluvial deposits. : clay slakes in 1 minute, is highly plastic, requires 32 per cent of er for molding, and shrinks 6 per cent on drying. Burning tests are 'ollows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	......	......
05	Red	2	13
1	Red	5	9
3	Red	6	8
5	Red	......	

e clay becomes hard at cone 05 (1922° F.) and has not reached :osity at cone 5 (2246° F.). It has thus a range of vitrification considerably over 300°, and should be capable of burning to thorough 'ification without loss. This clay is recommended for further estigation.

A mile south of Byron, at a bridge on the county road, there is a exposure of about 5 or 6 feet of Galena consisting of shale interbedde with limestone. This is not of as good quality as the sample from Fi more County. It contains a larger proportion of lime and requires higher temperature for thorough burning. Its plasticity is not high and the abundance of lime has a very strong tendency to destr the brick even after burning to as high a temperature as cone (2210° F.).

For 25 years a plant has been at work near the station of Byr on an extensive deposit of sandy yellow loess, 4 feet thick. Over million bricks per year were produced, but the plant was burned in 191 and has apparently been abandoned.

OTTERTAIL COUNTY

Types of clay, Pleistocene ....b) Gray lake cl
a) Gray drift

In the town of Fergus Falls a deposit of laminated clay was use 20 years ago for a rather soft and poor grade of yellow brick. The poo qualities of the brick were possibly due in part to the method of burnin but were probably due also to the sandy nature of the clay. Th clay is covered by a thin layer of soil and contains no pebbles. It quality seems to be satisfactory as to plasticity and range of vitrif cation. It reaches viscosity at cone 6. If market conditions are favo able, it may be worthy of further investigation. The hills south of Ferg Falls may contain similar clay.

Two miles north of the railroad station at Perham is a deposit laminated clay covering at least 20 acres and 15 feet in thicknes Yellow and blue-gray clays alternate in this deposit, the yellowis color due to oxidation having apparently followed the beds whic allowed more rapid circulation. A very few limestone pebbles and great many cylindrical ferruginous concretions occur in the cla The clay is capped by soil only. The working qualities of the cla are fair, though it is likely to crack in drying. It burns hard at co 12. The Northwest Brick Company has been producing commo yellow brick from it for nearly 40 years. Conditions are excelle except in the matter of railroad facilities.

At Deer Creek, the Deer Creek Brick Company has opened a p 4 miles northwest of town, in which are exposed 15 feet of yello clay and 15 feet of blue-gray clay, all laminated in horizontal layer It underlies from 3 to 6 feet of bowldery drift. Its working qualiti appear to be excellent and it burns hard and buff-colored at cone

with a good range of vitrification. The company, which was organized about five years ago, has been producing brick at the rate of about 10,000 per day, working on half-day shifts. The plant is not now active on account of the difficulty of reaching a market from its rather inaccessible location.

Laminated clays are known at two points near the town of Battle Lake. Here, Mr. A. C. Hatch established a brick yard, using a clay which he had found across the lake. The clay was mined by blasting when frozen, and hauled across the lake on the ice. A moderate success was made of a small plant, but the clay is nearly exhausted. Two miles southeast of Battle Lake on the banks of Clitherall Lake are many acres of a similar clay. It is at least 12 feet thick.

At Pelican Rapids, the following series of outcrops is observed in Sec. 22, T. 136 N., R. 43 W.

Gray drift	1 to 15 feet
Yellow laminated clay	12 to 14 feet
Blue laminated clay	4 to 6 feet
White sand	Bottom

The yellow clay was worked until 9 or 10 years ago, but the amount of overburden increased so as to render operations unprofitable. The working and burning qualities of the clay are fairly good. It makes a buff brick without any very great range of vitrification, and before burning it has only a medium tensile strength.

One mile north of Pelican Rapids is a very extensive clay bank of the gray drift which is known to be over 10 feet thick. This can hardly compete with the laminated clays near by.

PENNINGTON COUNTY

At Thief River Falls, which is in the region once covered by Lake Agassiz, a considerable deposit of clay 4 or 5 feet thick was used for brick many years ago. The best clay is now nearly exhausted. Excellent brick were made, and, if other alluvial clays are found, they may be suitable for development.

PINE COUNTY

Types of clay,	2. Recent	Swamp clays
	1. Pleistocene	Red drift and laminated clay

The red drift of most of the county is from the Lake Superior invasion, but older red drift lies below it and the gray drift extends

which can be traced all along the river and is known to a depth east 12 feet. It is covered only with soil and underlaid with a and blue clay of unknown thickness. There are a few limestone and limey and iron concretions. The lamination in the upper paper thin, but in the lower part of the bank there are layers nches thick. The working qualities of the clay are very good, that it cannot be dried rapidly without checking. It burns t cone 2, and has a fair range of vitrification. The plant is ing common cream brick by a soft-mud process, at the rate it 4 million in a season. The Crookston Brick and Tile Com- perate close to the saw mill on the same deposit. Where d in their pit, the clay is a little more sandy. The capacity plant is about the same. The City Building Inspector, of Min- s, in testing a set of 6 brick from this deposit at Crookston, a crushing strength ranging from 1,950 to 3,350 pounds per inch, with an average of 2,500 pounds. The blue clay of the levels gives the usual trouble in drying.

East Grand Forks the silts of the Red River extend for miles up own the valley and locally are 100 feet thick. They have been d and weathered yellow to a depth of 5 feet, and for many years ortion has been used for making cream-colored brick. On the ide of the river, work has been in progress over 20 years, and nd Forks, on the Dakota side, for a longer time. The same com- controls the yards in both Dakota and Minnesota. Steam shovels etter machinery have been installed on the Dakota side, and, if the nd is not great, the plant on the Minnesota side is closed, rather the other. According to the officers of the company the clay at wo plants is essentially the same. The clay slakes at once and its icity is very low. It requires 26 per cent of water for molding, shrinks less than 4 per cent on drying. Its tensile strength was above 100 pounds per square inch. Burning tests gave the fol- ng:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
03	Buff	0	36
1	Buff	2	30
4	Buff	3	28
6	Buff	......	......

: clay becomes hard at cone 01 (2066° F.), and reaches viscosity (2246° F.). It is capable of being burned to an excellent

th Dakota Geological Survey give the following results rial from Grand Forks:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
010	Orange	0.5	31
05	Pink	1.0	33
03	Cream	0.1	22
01	Cream to green	2.0	18

"The bricklets, except the one burned to cone 01, were not very strong. The clay was incipiently fused at cone 1, became rapidly vitrified at cone 3, and viscous at cone 4."

Two analyses of clay from near Grand Forks are available, the first of which is furnished by the company and the second quoted from the North Dakota Survey.[1]

Analysis of Silts of Red River Valley

Silica	48.30	51.27
Alumina	8.16	9.33
Iron oxides	2.84	3.52
Magnesia	4.93	2.31
Lime	16.34	11.15
Soda	p. n. d.	2.08
Potash	p. n. d.	0.50
Ignition	18.00	

The underlying gray clay on the Minnesota side was more plastic and showed a greater shrinkage than the yellow clay which was being worked. The preheating process referred to in the chapter on physical properties (page 9) would improve the working qualities of this gray clay. A burning test resulted in a brown brick instead of a buff one, and the temperature of fusion was a few degrees lower. The plant on the Minnesota side of the river has a capacity of about 50,000 bricks per day.

In the neighborhood of Lengby are several lakes in which clay deposits overlie common gray drift. There is hardly enough of the lake clay to be used alone, and the gray drift is, as usual, full of pebbles. The lakes could probably be drained off, and clay deposits reported to be of considerable thickness would be exposed. The good quality of the material for common brick is shown by some brick which were burned eight years ago for the village school.

POPE COUNTY

At Glenwood a small plant was at work many years ago upon a superficial leached deposit of gray drift from which most of the lime-

[1]Clapp, C. H., and Babcock, E. J., Fourth Biennial Report State Geol. Survey of North Dakota, p. 185.

stone apparently had been removed. As the town has grown, this particular deposit has been leveled off and subdivided into city lots, ınd no similar deposit has been developed in the neighborhood. Al-hough its working properties were fair as regards plasticity, shrink-ge, and strength, it does not burn hard until within a few degrees f the temperature of fusion. It is, therefore, not promising for hard-urned brick. The usual quality of gray drift is available, however, along ll the hills in the neighborhood and, if it should be developed near ıe junction of the railroads, a plant using the Hutchinson process ight be successful.

RAMSEY COUNTY

pes of clay, 2. Pleistocene	....	c) Red lake and river clay
		b) Gray lake and river clay
		a) Red and gray drift
1. Decorah shale		

The Decorah shale, which is so extensively used at West St. Paul in Dakota County, occurs also in Ramsey County, but property is too aluable for excavation at these localities.

The general section of the drift in Ramsey County is as follows:[1]

3. Loam	....	3-10 feet
2. Gray drift	(d) sand, gravel, and stone....	0-10 feet
	(c) laminated brick clay	0-16 feet
	(b) sand, gravel, and stone.....	20 feet
	(a) till (seen)	0- 2 feet
1. Red drift	(b) laminated brick clay	0-10 feet
	(a) till	10-20 feet

Leached gray drift has been used in the northern part of the city of St. Paul for red brick.

The red laminated clay is somewhat sandy, like that at Stillwater. It was once used on Dayton's Bluff. Just south of Como Park a thickness of 10 feet of red laminated clays is visible at the crossing of Lexington Avenue under the Northern Pacific Railroad. From 5 to 20 feet of gray drift lies above it. A sample was taken here as an indication of the quality of these clays in the neighborhood of the Twin Cities, where the gray laminated clays also are used. Tests by the U. S. Bureau of Standards are as follows: The clay contains too much fine sand to work well in an auger machine. The water

[1]Winchell, N. H., Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 371.

Cretaceous clay described below. The outcrops extend for nearly a mile along the river. The clay is well situated with respect to railroads, but, on account of its scenic features, the property at the exact point of outcrop is reserved as a State Park. As tested in the laboratory, the clay slakes in 1 minute. In plasticity it is low, requiring 33 per cent of water. The tensile strength is about 50 pounds per square inch, but it is not affected by rapid drying. It burned salmon color and hard at cone 1 (2100° F.). It became brown at cone 13, but was still undeformed. The tests indicate that it is a good grade of refractory clay. At one point in this gorge where the original rock was doubtless highly ferruginous the red stain of iron oxide is so great that a "Red Paint Mine" was opened, and a few tons of paint rock were shipped.

Between Redwood Falls and Morton, along the south bank of the Minnesota River, a test pit has been dug by the Morton Brick and Tile Company into a bank of residual decomposed gneiss. This has retained its granitoid texture, and the ferromagnesian minerals have changed to chlorite as the feldspar changed to clay. The resulting clay has a very mottled appearance. It burns to a gray color, becomes hard at cone 2 (2138° F.), and is thoroughly vitrified at cone 13 (2534° F.).

A sample of basal Cretaceous clay was taken near the town of Morton. South of the river on the road to Redwood Falls, where the road has been graded, there is an exposure in the river bluff which is one of the most instructive outcrops of Cretaceous in the State. The section is as follows:

Glacial drift	0 to 20 feet
Black shale	1 foot
Concretionary white shale	3 feet
Smooth white clay	3 feet
Concretionary clay with much coarse grit	5 feet
Conglomerate, quartz pebbles in a concretionary clay	2 feet
Decayed Archean granite and residual clay	5 to 8 feet

This is one of the thickest exposures of the basal Cretaceous known in this region, and shows a definite conglomerate at the contact with the Archean. (See Plate III, A.) Only a foot of Cretaceous shale is visible, but it is clear that the white clay grades into the shale without unconformity. Both the concretionary or pebbly clay and the white clay burn white and are undeformed at cone 33 (3254° F.), and are

therefore highly refractory fire clays. Even gritty varieties are fractory. Analyses are given in Table I, Chapter V.

The Morton Brick and Tile Company have made various attem to use the clay from this deposit in connection with their main depo which is alluvial clay of the Minnesota River. Mixtures of t refractory material with the alluvial clay have not been found to i prove the latter when only a small percentage of the fire clay w used. The deposit here is not large enough to justify attempts to p duce vitrified ware by the use of a high percentage of the fire cl It is not unlikely, however, that larger deposits might be found. T outcrop down the river in Renville County is said to be even thick and a similar stratum may be traced up and down the Redwood gor wherever the Archean clays form the main bank of the bluff. The scattered exposures may represent parts of a single large body of hi grade clay under the drift. Relatively small amounts of the fire cl have been worked up without the addition of other clays into f brick which had the same defects as those made at New Ulm, name lack of strength after repeated heating and cooling. The refracto ness is, however, all that could be desired.

As tested by the U. S. Bureau of Standards, these clays have t following properties: Plasticity is low even after grinding and usi 29 per cent of water. Drying shrinkage is 4 per cent. The burn color is not quite as clear a white as that of commercial kaolin. T softening point is above cone 32 (3220° F.). There is a rather se ous tendency to check in burning, even in hand-molded bricks. T clay needs a plastic fire clay bond in small amounts. Analyses by t Bureau of Standards are as follows:

Analyses of Basal Cretaceous Clays

	1.	2.
Silica	45.14	44.12
Alumina	37.94	38.39
Iron oxides	1.01	1.06
Titanium oxide	1.09	1.17
Lime	0.46	0.28
Magnesia	0.08	0.11
Soda	0.36	0.30
Potash	0.09	0.17
Ignition	14.10	14.70

1. The smooth white clay.
2. The pebbly or concretionary clay.

By washing, the color of this clay after burning might be made as go as that of commercial kaolins.

In Redwood County, near the town of Morton in Renville Coun the alluvium of the Minnesota River occupies a great many acres the river flat. Locally it is 10 feet thick. Under the sod there a

eet of black sandy clay, then 5 feet of yellow sandy clay, below ich is river gravel. The clay slakes at once, is highly plastic, and uires 27 per cent of water for molding. Its tensile strength is rly 100 pounds per square inch, though it may be somewhat less if the is dried too rapidly. The air shrinkage is 7 per cent. Burning tests as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0	22
02	Salmon	1	22
1	Brown	5	12
2	Brown	6	9

clay becomes too hard to be scratched with a knife at cone 05 22° F.), and reaches viscosity a little above cone 2 (2138° F.).

The Morton Brick and Tile Company have been manufacturing brick and drain tile for many years in a modern plant of medium acity. Small additions of the refractory Cretaceous clays do not prove the product.

RENVILLE COUNTY

ypes of clay, 4. Recent ....Lake clays
3. Pleistocene ....Gray drift
2. Cretaceous clays
1. Archean residual clay

Lake clays of unknown quality are reported at Boon Lake in the northeast corner of the county. The gray drift of most of the county s of the common type. From Beaver Falls east, along the Minnesota River, Archean residual clay and basal Cretaceous clays are important.

On Birch Cooley, three-fourths miles up the creek from the river bluffs, the "concretionary marl" reported by N. H. Winchell[1] reaches a great thickness. Well records show it at many other places below 100 to 300 feet of drift. This drift overburden is the chief drawback o its extensive development.

At a point two miles below the Lower Sioux Agency, Sec. 10, T. 112, R. 34 (in Birch Cooley), on the north side of the Minnesota, a small creek joins the river. Up his creek, about three-quarters of a mile from the river bluffs, the Cretaceous apears in its banks. A concretionary marl, or apparently limey earth, of a white color, rumbles out under the projecting turf. It appears in fragments of an inch or two, r sometimes larger, with angular outline. The surfaces of these pieces show a great umber of round or oval spots or rings, which seem to be formed by the sections of oncretions enclosed in the mass. It is rather hard when dry, and nearly white. It s associated with a blue clay, the relations of which cannot here be made out.

At a point a little further up this creek appears a heavy deposit of concretionary,

[1]Winchell, N. H., Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 197.

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	......	19
04	Salmon	1	20
01	Cream	......	......
2	Cream	......	......
5	Buff	10	......

The clay becomes too hard to be scratched with a knife at cone 02 (2030° F.), and is not viscous at cone 5 (2246° F.). There is some tendency to form black cores if the heating is too rapid, but with slow heating it can be safely vitrified. The temperature required for vitrification is slightly greater than the Decorah usually requires. The usual difference is found between the upper and lower layers, more limestone being included in the top. A test by the U. S. Bureau of Standards showed a tendency toward forming an efflorescence. This is probably due to the weathered condition of the sample. This location is a promising one for the development of a brick industry.

There are many extensive swamps in the county, and a sample was taken from one which extends over about 60 acres, 6 miles northwest from Faribault. The clay is overlaid with about 2 feet of soil and peat, and seems to be free from impurities except organic matter. The clay slakes in 4 minutes and develops high plasticity with about 30 per cent of water. It shrinks about 8 per cent on drying, and cracks very badly. Many brick fall to pieces. If sand were available in the neighborhood and market conditions were favorable, the clay might be available for common red brick. It is found to have a fairly good range of vitrification, reaching viscosity at cone 3.

ROCK COUNTY

At Luverne a plant has been active for the last 15 years, producing excellent brick and tile from the gray drift which covers a large part of the county and is worked here to a depth of 10 feet. The limey pebbles which occur in the drift here are said to have a less serious effect than elsewhere, and, though some of the product may be injured by their presence, there is only a very small per cent of loss by the crumbling of the brick and tile after burning. The larger pebbles are removed from the clay by the use of conical rolls. The plant has a capacity of about 50,000 brick per day.

In the neighborhood of Beaver Creek, on the south side of the road where the railroad crosses Beaver Creek, a sample was taken of the gray drift which seems to resemble that exposed in the surrounding country. It is somewhat more sandy than the average and contains many pebbles, some of which are limestone.

The sand-lime brick plant at Luverne should be mentioned.

ROSEAU COUNTY

A quarter of a mile from the station at Badger, the gray drift has been worked over somewhat by the waters of Lake Agassiz, and is rich enough in clay to make brick. The clay contains a rather high proportion of limestone pebbles, and owing to these, the product is inferior. A process for removing the limestone would make it more satisfactory.

At the town of Roseau are several acres of similar modified drift at least 10 feet thick. It is highly calcareous, but the limestone is not present as pebbles. In working and burning it shows a very much better quality than that at Badger. A few yellow brick were made from it several years ago.

ST. LOUIS COUNTY

Types of clay,	3. Recent	Swamps and lake beds
	2. Pleistocene	d) Gray laminated clay
		c) Red laminated clay
		b) Red drift
		a) Gray drift
	1. Huronian	Paint rock

Just south of the town of Tower is a swamp that extends over several hundred acres. Borings show 40 feet of clay near the center. Above the clay, which contains very few limey pebbles, are several feet of peat. The North American mine is close to this deposit, and its underground workings may eventually drain the swamp. The clay slakes at once, shows a high plasticity, and requires 39 per cent of water for molding. The air shrinkage is very great, and the clay can hardly be prevented from cracking. The tensile strength is consequently small. As tested by the U. S. Bureau of Standards, it gave the following: The color varies from light red at low temperatures to chocolate at higher temperatures. The porosity ranges from 28 per cent at cone 010 to 16 per cent at cone 06, and drops rapidly to 3 per cent at cone 04. The best burning temperature would be at about cone 04 (1958° F.). The range of vitrification is fairly good.

A plant was started to manufacture the brick and tile from this material, but difficulty was experienced in drying the ware. On account of its good range of vitrification this clay might be valuable for making sewer pipe if it developed enough strength in the burned ware and could be safely dried. It has a lower temperature of fusion than most sewer pipe clays and this is sometimes an indication of weakness. If a less

plastic material can be found in the neighborhood and mixed with this clay, its properties might be more satisfactory.

At Buhl, the Grant open pit mine has exposed by stripping, a considerable body of swamp clay overlying gray drift. This material must be moved in mining and, if care was taken to avoid mixing with the drift, it would be available for making common brick. It has much the same quality as that at Tower and could be used for similar purposes. Organic matter is present and it is necessary to burn slowly to avoid the production of black cores.

At the town of Floodwood is the dividing line between the gray laminated clays which occur from here west, and the red laminated clays which occur in the eastern part of the State. About a mile northwest of town on the McCormick farm, a well has been dug which passed 12 feet of yellow clay and 6 feet of gray clay. The deposit can be traced over several acres and may extend much farther. It is covered with only a thin soil. The clay slakes at once, has a rather low plasticity, requiring 24 per cent of water for molding. Its tensile strength is well above 100 pounds per square inch, and it shrinks 2.5 per cent in drying. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Buff	1	35
1	Buff	4	30
3	Buff	8	21
6	Buff	......	......

The clay becomes hard at about cone 1 (2100° F.), and reaches viscosity at cone 5 (2246° F.). This test was made on the yellow clay and a similar test on the blue clay showed a slightly greater tendency to shrink and warp.

Gravelly drift, both red and gray, may be found in the immediate neighborhood of Floodwood.

The red laminated clays exposed along the banks of the Savanagh River near its mouth at the southeast edge of town were also found in excavations. The exposure is 10 feet thick and the bottom is not seen. The clay slakes in 2 minutes, shows a fairly high plasticity, and requires 25 per cent of water for molding. A test by the Bureau of Standards shows that it needs lubrication to work in the auger machine. Its tensile strength is nearly 100 pounds per square inch and the air shrinkage, 6 per cent. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	20
04	Red	3	15
02	Red	8	6
01	Red	9	4
1	Red	11	.....

The clay becomes too hard to be scratched with a knife at cone 05 and reaches viscosity at cone 1. On account of the easy accessibility of several other types of clay, mixtures of this clay were also burned, but none seemed to show a greater range of vitrification, or other improvement in properties. At the lower porosities this clay shows a well-vitrified structure.

On the Mesabi Range, notably at Coleraine and Hibbing, bodies of clay are interbedded with the iron ore. Iron has been concentrated in the clay, but it is not rich enough to be an ore. It is highly colored and commonly known as "paint rock." The beds vary greatly in size and texture. Some of the clay is sandy, but some is smooth and plastic. Where the ore is found both above and below the paint rock, it is necessary to remove the paint rock in order to work the open pits. If a use could be found for this material, it could easily be separated from the rest of the dump, which consists largely of gravel overburden. At Coleraine 20 feet of paint rock is being removed. The paint rock slakes very quickly and is highly plastic, requiring 27 per cent of water. Its tensile strength is a little over 50 pounds per square inch, and its air shrinkage 4.5 per cent. In spite of its high content of iron, it does not burn hard below a temperature of 2200° F., but is viscous at 2500° F.

Above the iron ore is a formation known as the Virginia slate. At the Norman mine at Virginia, over 20 feet are exposed. This also is highly ferruginous, and is not plastic, even when powdered. It has very little tensile strength and does not burn hard at a temperature of 2300° F.

SCOTT COUNTY

Types of clay,	3. Recent	Alluvium
	2. Pleistocene	b) Gray lake clay
		a) Gray drift
	1. Cretaceous	

Alluvium occurs all along the Minnesota River and in the bluffs at many points gray laminated glacial clays are known. A sample of gray drift from 3 miles south of Shakopee contains many limestone pebbles. At La Huiller Mound, between Jordan and Shakopee, a white clay resembling the Cretaceous was sampled for the state museum by N. H. Winchell.

In Shakopee, river alluvium is known to extend over 20 acres to the unusual depth of 30 feet. A dark-colored clay some distance from the river is found to be more plastic than that closer to the river, and the two are mixed to produce the proper clay for soft-mud red bricks. Some repressed brick are made at this plant. The clay slakes in 3 minutes, and

its plasticity is rather low. It requires 23 per cent of water for molding and shrinks 4 per cent on drying. Its tensile strength is about 100 pounds per square inch, and is not much less if the clay is rapidly dried. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
02	Salmon	0	13
1	Brown	3	15
3	Brown	5	22
5	Brown	......	......

The clay becomes hard at cone 01 (2066° F.), and reaches viscosity at cone 4 (2210° F.). The plant has a capacity of about 3 million brick per season.

At Blakeley a deposit has been used in the manufacture of cream-colored brick. It consists of laminated clay about 30 feet thick, the upper half of which shows the common weathered yellow color, characteristic of these clays. The extent of the deposit is uncertain on account of the talus from the overlying hill of drift, but it can be traced for some distance along the Minnesota River bluff. There is the usual difference between the upper and lower clays. Neither shows a tensile strength as high as 100 pounds per square inch, and, while the upper clay shows an air shrinkage of 1.5 per cent, the lower shows over 5 per cent. A mixed sample such as is used at the plant shows the following characters:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
1	Buff	1	30
3	Buff	5	20
4	Buff	......	2

Clay becomes hard at about cone 1 (2100°F.), and is near viscosity at cone 4 (2210° F.). A plant established here has been operated steadily since about 1890, making common brick. Recently a large proportion of hollow brick have been made with a stiff-mud machine which has a capacity of about 35,000 brick per day.

At Belle Plaine, in this county, a plant is in operation about a mile south of the town. The clay bank shows the following section:

Gravelly drift	30 feet
Yellow silt	10 feet
Gray clay	15 feet
Very dark gray clay	15 feet

The different portions of the bank are not regular in their stratification, but the clay seems to have been thrust up in a sort of arch in

this neighborhood and each part of the section grades into the overlying and underlying parts. The yellow silt of the section can be used as sand in tempering the lower clay. The working properties of the clay are excellent, and the plant which is operating can produce about 30,000 soft-mud cream-colored brick per day.

SHERBURNE COUNTY

Types of clay, Pleistocene................c) Gray lake and river clays
b) Red drift
a) Gray drift

An area in the neighborhood of the town of Elk River is covered with red drift, without the overlying mantle of gray drift found in most of the county. The sample taken slakes in 4 minutes. After grinding, it shows a high plasticity and a shrinkage of 8 per cent on drying. The tensile strength is, however, only a little over 50 pounds per square inch. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	16
04	Salmon	1	15
02	Salmon	3	12
1	Red	6	3

The clay becomes hard at cone 05 (1922° F.), and reaches viscosity at cone 1 (2100° F.). With this red drift available, there is little need of using the gray drift for common brick.

Two miles south of Sauk Rapids, and across the Mississippi River opposite some brick yards in Stearns County, there was at one time a brick yard producing cream-colored brick from yellowish laminated clay of the common type.

SIBLEY COUNTY

Gray drift covers nearly all the county, except along the Minnesota River where alluvium is found. The latter makes fair red brick. At Henderson, if the richer clay is selected from the deposit, 50 per cent of sand from the bed of the river is added for making sand-mold brick. The clay without the additional sand shows a rather high air shrinkage and, though its range of vitrification is about the average, it reaches viscosity at cone 1 (2100° F.). With sand added, this clay would no doubt have the properties of the other alluvial deposits. The plant is capable of producing about 10,000 red brick per day.

STEARNS COUNTY

Types of clay, 4. Recent ....Lake clay
3. Pleistocene ....c) Gray lake and river clays
b) Red drift
a) Gray drift
2. Cretaceous ....b) Shale
a) Basal clay
1. Archean ....Residual clay

The gray drift is abundant in the county but where tried at Collegeville and near St. Cloud, it was not satisfactory.

Just west of Richmond at the west end of a wagon bridge over Sauk River, is an exposure of Cretaceous, which has been explored by shafts and tunnels in search of coal. Gray shales outcrop above water level. A hole about 100 feet deep reached granite, but passed a large mass of basal Cretaceous and, below it, a white gritty clay retaining some traces of granitoid texture. This is probably decayed Archean granite. The section resembles that exposed in Redwood County. The gritty clay is plastic and has an air shrinkage of 4 per cent. At cone 04 (1958° F.) it is buff and too hard to be scratched with a knife. At cone 13 (2534° F.) it is purple, but still undeformed and very porous.

At this Richmond outcrop the bottom of the basal conglomeritic clay is below water level in the river. A boring into the hard clay at water level to test the thickness of the formation, showed at least 6 feet of white clay below, and 7 feet may be seen outcropping above water. It cannot be said with certainty where this Cretaceous formation ceases and the residual Archean comes in below, for they are of similar character.

This basal Cretaceous is overlaid with a dark gray shale and some small lignite layers. A near-by shaft 25 feet deep passed a 6-inch layer of lignite enclosed in blue clay which was proved to reach a depth of 50 feet by boring in the bottom of the shaft. Shale of the same general appearance was observed in a ravine 2 miles north of Richmond. A sample of the clay slakes in 3 minutes, and is fairly plastic, though it has a somewhat waxy feel apparently on account of included mica scales. It requires 16 per cent of water for molding. Burning tests by the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
011	Salmon	0	14
07	Salmon	0	13
05	Salmon	......	......
02	Salmon	......	......

The clay becomes too hard to be scratched with a knife before reaching cone 011 (1688° F.), and, if carefully burned, can be heated to cone 02 without deformation. The presence of organic matter, however, is responsible for the production of black cores with great swelling and cracking if the clay is not thoroughly oxidized. The range of vitrification is sufficient to make it perfectly safe to burn this clay to a dense product, but, owing to its low fusion temperature, it is not desirable material as a binder in making refractory ware of the non-plastic kaolins which underlie it.

Three miles south of St. Cloud the laminated clays are developed over many acres of land, along the west bank of the Mississippi. They have a thickness of over 30 feet, but over much of the surrounding territory they are deeply buried under deposits of sand. Here, a tributary stream, Three Mile Creek, has eroded the sand, and made the clay accessible. Two brick yards are at work upon the material. As usual the clay has irregular pockets and layers of sand, which, when rather fine, are called quicksand. These sands make very poor brick, but if proper attention is paid to the mixing of the plastic and sandy parts of the deposit, excellent cream-colored brick can be produced. The clay burns hard at cone 03, and has a range of vitrification much like that of other laminated clay. Both solid brick and hollow tile and building block are produced at each place, and each plant has a capacity of over 20,000 brick per day. At one plant round down-draft kilns are being installed so that the temperature of the burning of the tile can be more accurately controlled. A little farther south a similar deposit has been worked at St. Augusta. Work was started here in 1890, but was abandoned in 1910.

At Collegeville, for the buildings of St. John's College, brick were made from a small deposit of yellowish laminated clay which seems to be entirely surrounded by coarse gravelly drift. It may be only a fragment of some larger deposit which was caught up by a later ice invasion and deposited in the midst of a gravelly moraine. It shows the usual range of vitrification, reaching the point of fusion at cone 3 (2174° F.). The deposit is small and relatively inaccessible.

Brick have been made at Albany from clay obtained in the banks of a stream at the southwest side of town. It is said that the clay near water level is quite free from lime pebbles and burns red. At the top of the bank, the gray drift is full of limestone fragments and is unsuitable for brick manufacture without some cleansing process.

At Miers Grove, in this county, over several acres north of town the gray drift has been leached of some of its lime contents. The thorough leaching extends to a depth of only 3 or 4 feet and apparently the original

deposit contained a great many other pebbles besides those of limestone. The clay slakes in 3 minutes and is fairly plastic, requiring 29 per cent of water for molding. Its pebbly character keeps its strength somewhat below 100 pounds per square inch. Its air shrinkage, however, is nearly 7 per cent. The plant which has been working this clay for a local brick supply has a capacity of 20,000 brick per day, but the product is a very weak red brick.

Near Paynesville, a brick plant has been started to make use of a delta deposit on the shore of Eden Lake, near the mouth of the incoming creek. This was used to a depth of 16 feet without finding bottom, and is known to extend over 8 acres with a much larger area under the water of the lake. Water had to be pumped from the pit which extended below the level of the lake, but the seepage through the clay was relatively slow. The clay slaked at once, was highly plastic and required 21 per cent of water for molding. It shrinks 3 per cent on drying and has a tensile strength of about 150 pounds per square inch, even when rapidly dried. It burns to an excellent quality of red brick. The plant made stiff-mud brick with a capacity of 30,000 per day.

STEELE COUNTY

Deep well sections show the presence of Decorah and overlying shales at several localities beneath the drift, notably at Owatonna. Fire clay was reported a mile east of Owatonna.[1] It is not now used.

Half a mile west of the station of Meriden on the Northwestern Railroad, is a deposit of clay several feet thick. It extends over at least 60 acres, and resembles the loess, but, since it lies in a swamp, it is not all exposed and it may contain some glacial and recent sediments in addition to the loess. The clay slakes at once and shows a rather low plasticity. It requires 27 per cent of water for molding, and its air shrinkage is less than 4 per cent. Burning tests yield a light brown brick, without much shrinkage, and with an absorption of 30 per cent. Its range of vitrification, however, is only about 40° F., so that it can not safely be burned to a hard product. An analysis by Dr. E. P. Harding, of the University of Minnesota, is as follows:

Analysis of Loess Clay

Silica	60.00
Alumina	11.45
Iron oxides	3.90

[1] Harrington, M. W., Final Rep. Minnesota Geol. and Nat. Hist. Survey, Vol. 1, p. 402.

Magnesia	4.05
Lime	6.48
Potash	4.09
Soda	2.84
Moisture	2.32

The clay does not seem to be as promising as some of the other deposits of loess.

STEVENS COUNTY

Stevens County has a cover of gray drift which, where modified by water action, as at Morris, makes fairly good brick. At other points brick could be made from the drift only after the removal of limestone, but recent lakes may contain some good clay.

SWIFT COUNTY

Types of clay,	3. Recent	Alluvium
	2. Pleistocene	Gray drift
	1. Archean residual clay	

Gray drift and its outwash are the chief deposits in the county and neither is very promising except for common brick. Alluvium is of small importance. Decomposed granite was found in a well at Benson at a depth of 400 feet, and drilled into for 300 feet. At Appleton and elsewhere decomposed granite is closer to the surface. At Benson some sandy surface clays in the nature of outwash or loess and surface wash were used for red brick, but were found too full of limestone for good products.

TODD COUNTY

Types of clay,	2. Recent	Lake clays
	1. Pleistocene	c) Gray lake clays
		b) Red drift
		a) Gray drift

Most of the county is covered with gray drift and many attempts to use it have failed on account of the lime pebbles it contains.

The most important of the laminated clays is a deposit on Sauk Lake, most easily reached from Sauk Center, in Stearns County, three or four miles to the south. The clay bank rises steeply from the shore of Sauk Lake to a height of 15 or 20 feet, and extends under the level surface several rods back from the top of this bank. The

clay directly underlies the soil, although in some places the upper beds are somewhat sandy. Pits have been opened at numerous points along the shore, and the section exposed varies considerably in different parts of the bank. Limey concretions occur in a few spots. It is reported that the best clay occurs at water level. This is gray in color, while the main part of the bank above water level is yellowish white. Warren Upham concluded[1] that this clay accumulated in a channel in the melting ice sheets while a large mass of ice still occupied the basin of Sauk Lake. From the different clays in the bank a variety of products have been made, including both red and cream brick, hollow brick, terra cotta, and flower pots. Samples were taken of both the yellow and gray clays. The gray clay shows greater shrinkage and tendency to crack than the yellow clay. While the average air shrinkage is 3.5 per cent, the blue clay showed 5.5 per cent. The average of the bank gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0.5	21
02	Salmon	1.0	22
2	Buff	5.0	14
3	Buff	......	......

The clay burns hard at cone 02 (2030° F.), and becomes viscous at cone 3 (2184° F.).

Mr. David Pangburn, who has taken the lead in the development of the deposits and in experimental work to show the availability of the clay, has now retired, and active work upon the deposit has been dropped. Plans are in progress for reorganizing the industry, and it is thought that with the large amount of good clay available excellent products will be turned out, and shipping facilities will be provided.

At Clarissa Spur, near the station of Clarissa, in this county, a plant is making use of a sandy laminated clay. The clay is known to be 12 feet thick with an overburden of only 2 or 3 feet, and extends over several acres. The clay slakes in 4 minutes, and has a rather low plasticity, and an air shrinkage of less than 3 per cent. The tensile strength is nearly 150 pounds per square inch. The range of vitrification is from cone 1 (2100° F.) to cone 5 (2246° F.), or more. Brick are made by the soft-mud process and the plant has a capacity of 10,000 brick per day.

From one to two miles east of Staples along the Northern Pacific Railroad, are several acres of laminated clay, known to extend

[1]Upham, Warren, Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 578.

to a depth of 6 feet. These have been worked at two brick plants for common red brick and are said to contain too many limestone concretions if worked to a greater depth. The plants have a combined capacity of about 40,000 brick per day, but they are not now in operation. The clay slakes in 2 minutes, is highly plastic, requiring 28 per cent of water for molding. The tensile strength is over 100 pounds per square inch, but there is danger of cracking if rapidly dried. The air shrinkage is nearly 6 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	25
03	Salmon	2	23
01	Salmon	2	23
1	Green	......	......

The clay becomes hard at cone 03 (1994° F.), and is viscous at cone 1 (2100° F.).

At Birch Lake, in this county, the railroad passes the north shore of the lake about a mile east of town, and many years ago a brick plant made use of some laminated clay found along the shore. It may be in part a relatively recent formation, but is probably also partly of glacial age. The character of the clay is very similar to that at Sauk Lake, just described, but its extent is not well known.

Just southwest of Burtrum, two brick plants have been built to use clays which consist of outwash from the drift. The beds are sandy and irregular, but can be traced over many acres, and are exposed in some places to a depth of 16 feet. The clay slakes at once, and its plasticity is low. It requires 21 per cent of water for molding, and shrinks about 5 per cent on drying. Its tensile strength is nearly 200 pounds per square inch, though somewhat less if rapidly dried. The clay burns salmon-colored at low temperatures, but buff or green at higher temperatures, indicating the presence of considerable lime. This lime is probably derived from wash from the gray drift, which extends nearly up to this point. The clay burns hard at cone 01 (2066° F.), and reaches viscosity at cone 4 (2210° F.). Neither of the plants is now in operation, although the material seems to be fairly good.

In the midst of the gray drift in the morainic belts, there are a great many pot holes where the wash from the gray drift has accumulated in swampy places. Two miles west of Long Prairie a brick yard has made use of some small deposits of this sort for a common red brick. The deposits are nearly worked out and it is not likely that others will be started as no others are so easily accessible. A similar deposit occurs about half a mile east of Eagle Bend, and

everal years ago was used for a kiln of brick. It is small and contains many limestone pebbles.

TRAVERSE COUNTY

Types of clay, 2. Pleistocene ....Gray drift
1. Cretaceous

Gray drift somewhat modified by Lake Agassiz is the chief available clay.

There is an indication that a very large part of the county is underlaid by Cretaceous clay. Most of it, however, is covered with glacial drift and is not readily accessible. Across the river, in South Dakota, is an exposure that was brought to our attention by Mr. A. Parker, of Brown Valley. The clay is at least 40 feet thick and probably much more, and extends for miles along the valley. It is a stratified clay with blue and yellow layers and where it was sampled the glacial drift above it is about 20 feet thick. It is in a situation favorable for excavation, but is a mile from any railroad. The clay slakes in 4 minutes, and is highly plastic, requiring 34 per cent of water for molding. It has a tensile strength of over 100 pounds per square inch even if rapidly dried. It has the further desirable quality of developing considerable strength after being slightly compressed even if it has been separated into several parts as in the auger machine. This is one of the few clays tested which developed this adhesive character. Its air shrinkage is 11 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	4	9
02	Red	7	3
2	Red	......	......
3	Red	......	......

The clay becomes too hard to be scratched with a knife somewhat below a temperature of cone 010 (1742° F.), and is still undeformed at cone 3 (2174° F.). The range of vitrification is about 400°. If rapidly heated, there is organic matter enough present to cause swelling and the formation of a black core, but, if thoroughly oxidized, this can be easily avoided. The analysis of the clay is given in Table II.

WABASHA COUNTY

Types of clay, 3. Recent ....Alluvium
2. Pleistocene ....b) Loess
a) Gray drift
1. Cretaceous

At the town of Wabasha a plant was in operation for about 2 years on a deposit of loess loam on a terrace of the Mississippi Rive It has a thickness of 4 or 5 feet for at least 40 acres. Although th loess is rather sandy, it produced a good red brick. About 500,0C brick were manufactured per year, but work was stopped about years ago on account of poor market conditions.

Half a mile from the station of Elgin, in this county, loess loai to a thickness of 12 feet overlies a deposit of stratified sand, over a area of 25 or 30 acres. A small hand mold brick plant has been i operation for over 30 years, and the capacity of the plant has bee about 250,000 bricks per season. A similar deposit occurs near th station at Plainview, and was used for a time.

The alluvial clays along the Mississippi River have not bee worked and it is unlikely that they will prove to be of much valu The gray drift covers most of the county, but is inferior to the loes and alluvium.

Cretaceous clays probably exist in Wabasha County, althoug none have been seen in place. Small pieces of clay similar to th Cretaceous clays of Belle Chester and Clay Bank were observed a numerous places in the glacial drift. It is not improbable that carefu prospecting would result in the discovery of local deposits of Creta ceous clay in the northern part of the county, for example at Oak Center

WADENA COUNTY

Several attempts have been made to use the common gray drift but the limestone caused the usual difficulty and no one has estab lished the necessary process for removal of the pebbles. The tow of Wadena is favorably situated for such an establishment.

WASECA COUNTY

Gray drift was formerly used for common brick at several sma yards. Possibly glacial or recent lake clays worth developing will b found. The Decorah shale is buried deeply under the drift.

WASHINGTON COUNTY

Types of clay, 2. Recent ....Lake clay
1. Pleistocene ....b) Red lake clays
a) Red and gray dri

rest Lake Brick and Tile Company has a pit south of Fo long the Northern Pacific Railroad. This is situated i hich is a little less gravelly than the usual type. At th

plant the clay is ground, but limestone pebbles are not removed. The capacity is about 10,000 red brick per day. The clay slakes very promptly and shows a fairly high plasticity. Its air shrinkage is 4 per cent and its tensile strength is about 125 pounds per square inch. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Light Red	......	......
03	Red	0.7	14
01	Red	1.0	12
2	Red	......	......

The clay becomes hard at cone 03 (1994° F.), and shows no sign of becoming viscous at cone 2 (2138° F.). Although it might be improved by the removal of the limestone pebbles, it seems to supply a satisfactory product after simple grinding. It must be burned, however, to a fairly high temperature or the lime particles will greatly weaken the product.

The plant was first built here to use red drift that was loaded on cars, hauled a quarter of a mile to a barge which transported it several miles across the lake. The cost of transportation was heavy and it was abandoned for the more accessible gray drift. The sample taken indicates, however, the excellent quality of the red drift of the region. It slakes at once and after the gravel has been crushed to 40-mesh, the plasticity is fairly high. The tensile strength is considerably over 100 pounds per square inch even after rapid drying. The water required for molding is 20 per cent and the air shrinkage 4.5 per cent.

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
07	Red	1	15
05	Red	2	14
1	Red	7	5
3	Red	8	4

The clay becomes hard at cone 06 (1886° F.) and is approaching viscosity at cone 3 (2174° F.).

At a point two or three miles south of the town of Afton, a sample of a clay that seems to be red drift was obtained. This is much less pebbly than the average red drift and shows the usual good range of vitrification. The material is not especially accessible to any of the large markets.

At Stillwater, red laminated deposits occur along Brown's Creek, just above its mouth. These were described by N. H. Winchell[1]

[1]Winchell, N. H., Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 394

tripoli, because they were rather more gritty than most o minated deposits discovered. Winchell, however, notes the oility of its having an origin similar to that of the red lamir lays at St. Paul and elsewhere. The clay slakes in 1 minute, is ery plastic, and requires only 20 per cent of water for molding. tensile strength is a little less than 100 pounds per square inch, but i be dried rapidly without injury and even after it has been cut in tw again pressed together in the plastic state as in the auger machin shows considerable strength. The air shrinkage is only 2.2 per Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	20
03	Salmon	2	17
01	Red	5	10
1	Red	6	3
3	Red	......	......

The clay becomes hard at cone 02 (2030° F.), and reaches viscos at cone 2 (2138° F.). Analyses are given in Table IV (page 52). account of its low temperature of fusion, it was tested as a slip clay and preliminary tests it proved very satisfactory.

Just south of Stillwater, the shores of Lily Lake consist of clays of a quality suitable for hard common red brick. They known to exist to a depth of 10 feet over several acres. They a conveniently situated as regards market. There is no railroa the clay, and there is a steep hill between the lake and the Stillwater. The excellent quality of the clay, however, is the following tests. It slakes in 2 minutes, and is very high requiring 19 per cent of water for molding. It shrinks a 3 per cent on drying and has a tensile strength of nearly per square inch. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage
06	Salmon	1.0
02	Red	2.0
1	Red	4.0
3	Red	5.5
5	Red	......

The clay burns hard at cone 02 (2030° F.) and is (2246° F.).

WATONWAN COUNTY

Types of clay, 2. Recent L
1. Pleistocene C

In this county most of the surface material under the soil is typical gray drift, although the kettle holes and swamps contain some clay washed from the hills of gray drift. A sample of the drift, taken from Sec. 13 near St. James, would require the removal of the limestone pebbles for the successful production of brick or tile.

The swamp clays seem to be of excellent quality. Samples were taken from a deposit 2 miles northeast of Madelia, where a brick yard operated some 13 years ago. Sand was mixed with the clay and the product made a light red brick. At Odin a similar deposit was sampled. This has been thoroughly prospected but has not yet been developed. There are several acres of the clay known to be 16 feet thick. Burning tests at the Minnesota School of Mines Experiment Station gave the following results:

Madelia Clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0	
03	Salmon	1	24
1	Salmon	2	21
3	Brownish gray	3	14
5	Yellowish gray	......	......

Odin Clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Red	0	15
03	Red	1	14
01	Red	3	11
2	Red	4	7
3	Red	5	5

Both these clays are highly plastic, dry safely to a strong brick, and show an excellent range of vitrification.

WILKIN COUNTY

Wilkin County has only the common gray drift modified north of Breckenridge by Lake Agassiz and the Red River.

About a mile north of the town of Breckenridge, a brick yard has been operated occasionally since 1880 on clay which outcrops in the east bank of the river. The thickness of the deposit is known to be 30 feet in some places, but as here exposed and weathered, only about 10 feet are available. The clay slakes in 4 minutes, is highly plastic, and requires 23 per cent of water for molding. The air shrinkage is 14 per cent and it has a tendency to crack in drying. It burns hard at an unusually low temperature, below 1700° F., and on being burned to higher temperatures has a further tendency to crack.

Three miles southwest of Winona is a deposit which shows the following section:

Soil	6	inches
Sandy yellow loess	2	feet
Very plastic red clay	14	inches
Plastic yellow massive clay	3½	feet
Stratified yellow sandy clay	4	feet

A sample taken includes all of the section except the soil. Each clay slakes in a very few minutes and develops a fairly high plasticity. The mixture requires 36 per cent of water for molding, has an air shrinkage of 10 per cent, and shows a strong tendency to crack on drying. When properly burned it forms red bricks which become hard at cone 010, (1742° F.). When rapidly burned, black cores develop and organic matter destroys the brick. If slowly burned it does not become viscous at a temperature of cone 02 (2030° F.). It has thus a range of vitrification of about 300° F. and can be burned safely to a fairly good hard product.

Near the clay just described alluvium has accumulated along Burns Creek. This extends over more than 40 acres and is 12 to 14 feet thick. The clay is blue-black and very plastic, and most of it is free from pebbles. The clay is used for mixing with the clays in the same neighborhood, but the plant is at a disadvantage in being located some distance from the railroad. The alluvial clay slakes in 4 minutes and requires 23 per cent of water for molding. Its air shrinkage is 2.5 per cent. It burns salmon color at low temperatures, but becomes brown when well vitrified. It becomes hard at cone 01 (2066° F.), and is not yet viscous at cone 4 (2210° F.). About three million brick are produced each season at this plant.

The Decorah shale occurs in a small area in the southwestern corner of the county, near the town of St. Charles, where it outcrops 40 feet thick under 30 feet of drift. The shales of the St. Lawrence formation outcrop at Dresbach, but are thin. A sample taken does not slake, and retains a porosity of 20 per cent up to cone 4, when it becomes gray in color and hard.

WRIGHT COUNTY

Types of clay,	2. Recent	b) Alluvium
		a) Lake and swamp beds
	1. Pleistocene	b) Gray lake clay
		a) Gray drift

Gray drift covers most of the county. At Otsego an attempt to use the drift failed on account of the limestone contained. Two or three attempts have been made to use the deposits around Buffalo. Many thousand brick have been made from the upper leached portion of the drift where it is relatively free from limestone.

At Dayton, near the mouth of Crow River, laminated clays, which show the usual characteristics, have accumulated in great quantity. A brick yard owned by Mr. Prosper Vassar has exploited these clays since 1880, and has thus far used only the upper leached portion of the deposit. This has a few limey concretions, but has yielded excellent common brick for local use. The lower blue clay is more plastic, requires more water for molding, and shrinks about three times as much. Burning tests of the yellow clay are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Buff	0	34
1	Buff	2	30
3	Buff	6	22
5	Buff	......	......

The clay becomes hard at cone 1 (2100° F.), and shows no sign of viscosity at cone 5 (2246° F.). The underlying blue clay, which shows great shrinkage, shows also a lower temperature of vitrification, having apparently reached viscosity before the yellow clay has become hard. There was some tendency also towards the formation of black cores. At the brick yard, brick are molded with a stiff-mud machine, having a capacity of 30,000 brick per day.

Up the river from this deposit, there is good laminated clay near St. Cloud, but between the two deposits, a mile or more from the town of Hasty, is a deposit which appears to be similar but which behaves differently. Many of the brick check badly in burning. The sample taken slakes in 3 minutes and is very highly plastic, requiring 36 per cent of water for molding. It shows an air shrinkage of 10 per cent and, even when carefully dried, shows a tensile strength not over 10 pounds per square inch, indicating that the shrinkage had caused cracks which weakened it. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	2	22
05	Salmon	2	24
03	Salmon	3	21
1	Greenish yellow	10	5

The clay becomes hard at cone 06 (1886° F.), and had not yet reached viscosity at cone 1 (2100° F.). Apparently the only difficulty with

the clay is the tendency to crack on drying, though there may be some serious trouble from the laminated structure due to the auger machine, which is used in the manufacturing. These difficulties could be easily remedied if a more sandy layer could be found for mixing with the clay now used.

At Annandale in the western part of the county, the Annandale Brick and Tile Company have built a plant on the Soo Line a mile east of town to use a deposit of laminated clay known to cover several acres, with a thickness of at least 15 feet. It is covered only with soil and has but few limey or ferruginous concretions. Traced for 200 yards eastward along the track, it is found to be very much more sandy and of inferior quality. The clay where used is found to contain sufficient sand, so this sandy part of the deposit remains untouched. In working and burning qualities, the clay seems to be excellent, but some difficulty has been encountered at the plant in getting the clay to dry without cracking.

In Sec. 27, T. 120 N., R. 25 W., which is about two miles and a half from Buffalo and a mile and a half from the railroad, there is a rather extensive swamp which has been drained by a state ditch. The material thrown out from this ditch contains fragments of shale in great abundance, and it is relatively free from limestone. It is noticeably different from the gray drift as generally developed. Such material has not been noted in the present work in any other part of the State except in the neighborhood of Alexandria. The clay slakes at once, and is highly plastic, requiring 25 per cent of water for molding. Its air shrinkage is 5 per cent and its tensile strength is 150 pounds per square inch, though it checks rather badly on drying. Burning tests by the Minnesota School of Mines Experiment Station gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Red	.5	17
02	Red	1.5	16
1	Red	2.5	14
3	Red	4.0	11
5	Red	......	......

The clay becomes hard at cone 02 (2030° F.), and shows no sign of becoming viscous at cone 5 (2246° F.). It has thus a range of over 200° F. during vitrification, and the cross fracture of a well-burned brick suggests that it would be good material for paving brick. Simple laboratory tests show that it is both hard and tough. The deposit appears to warrant further prospecting.

A lake deposit is formed along the shores of Lake Mary, 6 miles

from the station of Howard Lake. The material is mixed with coar sand available in the same neighborhood. Soft-mud red brick a manufactured at the rate of 250,000 per year.

At Monticello, brick were made some years ago from a very san clay in the banks of the Mississippi River which is probably alluvia The deposit seems to contain less than 20 per cent of clay substance, a yields a common red brick of poor quality.

YELLOW MEDICINE COUNTY

Yellow Medicine County is covered with gray drift. Brick we once made near the town of Yellow Medicine.

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The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY
William H. Emmons, Director

IN COÖPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 12

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS OF NORTHWESTERN MINNESOTA

BY

FRANK LEVERETT

WITH A CHAPTER ON

CLIMATIC CONDITIONS OF MINNESOTA

BY

U. G. PURSSELL

Minneapolis
The University of Minnesota
1915

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INTRODUCTION

By W. H. Emmons

The natural economic assets of an area, such as its soils, clays, building stones, iron ores, etc., all bear a direct relation to the geological features of that area, and a rational discussion of such assets must give due importance to the geological history and environment of the area which contains them. The last, and, therefore, from the standpoint of the soils and surface features of the country the most important, great geological event that has affected this area is the invasion of sheets of ice that moved southward from the Canadian highlands carrying with them rocky material which they had gathered in the north. When the ice melted it left large quantities of rock and soil and in the area here described this material nearly everywhere now forms the surface.

The last great ice sheet that covered this area melted very slowly and the southern part was melted long before the northern part. The ice that still remained in the north formed a great dam which held back the drainage of the Red River Basin and formed a large lake which is called the glacial Lake Agassiz. This lake overflowed southward through the Minnesota River and into the Mississippi. These conditions endured through a long period and this lake was partly filled with material that washed into it and its bottom was washed and smoothed over by waves and shore currents. Later, when at the north the ice dam melted, the lake was drained to the north, and its bottom now forms one of the largest and richest agricultural regions of the world. This lake was drained very gradually, however, its level remaining stationary through considerable periods so that gravel beaches were formed here and there along its shores. These gravel beaches supply material for roads and they furnish also attractive building sites for farmhouses and barns.

After the ice had melted, large swamps and marshes occupied poorly drained portions of the region and many of them remain to the present day. The drainage and reclamation of these lands is one of the most important problems of this region.

The great productivity of Minnesota soils is due, not only to their recent origin by reason of which nearly all of them still contain the soluble mineral foods for plants, but also to a very favorable climate. The low temperatures which frequently prevail during certain periods in winter make for healthful conditions for animal life and they also benefit plant life. The rainfall, though not excessively great, is sufficient and, since most of it occurs during the growing period, drouths are rare and crop failures almost unknown except in the more sandy soils, which

are, however, adapted to quick-growing crops like potatoes. As shown herein, the length of the crop-growing season, that is, the time between late spring frosts and early autumn frosts, is between 100 and 170 days for all except the extreme northeast corner of the State, and in the southern half is nearly everywhere above 130 days, a period that is ample for growing the highly productive crops of Indian corn. The long days, high proportion of sunshine, and the moderate humidity are all favorable to plant growth.

This bulletin is a preliminary paper which treats the soils of only the northwest quarter of Minnesota. It will be followed by a report on the entire State, the field work for which will soon be completed. The work has been done in accordance with the agreement for coöperation between the United States Geological Survey and the Minnesota Geological Survey, entered into March, 1912. By this agreement the services of Professor Frank Leverett were secured for surveying the surface formations and soils. Mr. Leverett has been engaged for some twenty years in studying the surface geology of the Great Lakes region and because of his large experience in the greater area he is particularly well prepared to undertake the studies in Minnesota. He has spent, moreover, considerable time in the State studying its physiography in connection with the preparation of a monograph for the United States Geological Survey. Since the reorganization of the State Survey, the salary of Mr. Leverett has been met by the United States Geological Survey, while the greater part of his expenses have been paid by the State Survey. The State Survey has provided also for this work the services and expenses of Professor F. W. Sardeson, who has assisted in this work for the past three seasons. For brief periods, also, the State has supplied the services of Arthur H. Elftman, P. R. McMiller, and G. R. McDole. We wish to acknowledge the generous assistance of the Division of Soils of the Department of Agriculture of the University of Minnesota and of the United States Bureau of Soils, both of which have contributed unpublished data. The valuable contributions to the knowledge of the surface formations of Minnesota by the Minnesota Geological and Natural History Survey, under the direction of Professor N. H. Winchell, particularly those of Mr. Warren Upham of that Survey, have aided greatly in the preparation of this report. The section on climatic conditions in Minnesota has been generously contributed without any cost to the Survey by Mr. U. G. Purssell, Director of the Minnesota Section of the United States Weather Bureau. In the preparation of the maps and other data showing dates of killing frosts, lengths of growing season, rainfall, etc., Professor C. J. Posey has rendered efficient service.

The cost of preparation of this report has been met by the Minnesota Geological Survey and the United States Geological Survey. This

bulletin is printed by the Minnesota Geological Survey. Arrangements will be made so that land and colonization companies can secure these reports at actual cost of printing, and it is expected that this arrangement will secure a wide distribution. The maps are not intended to be used as a basis for the purchase of land; they do not give an accurate description of each forty-acre tract or each section, but they show the general classification of the land, its climate, and its surroundings.

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS IN NORTHWESTERN MINNESOTA

By Frank Leverett

FIELD WORK AND ACKNOWLEDGMENTS

This report treats particularly the northwest quarter of Minnesota, but a brief general description of the surface features and deposits of the entire State is given because the larger area makes a more natural unit for purposes of description. For this reason, also, Mr. Purssell has discussed the climate of the entire State. In this report no attempt is made to measure the crop-growing capacity of any class of soil, or the adaptation of certain soils to particular crops. These matters fall naturally to the Department of Farm Management. It seems pertinent, however, to note that soils which are classed as light may under intelligent management be made to yield returns which compare favorably with the yield from heavier soils. The sandy areas shown on the map which accompanies this report thus afford an inviting field for experimentation. The drainage and utilization of the great swamps constitute another large field for intelligent operation.

The productiveness of a soil usually has some relation to its origin and to underground conditions. It therefore means more to say that a given soil is a glacial lake clay or a lake sand than merely to call it a clayey soil or a sandy soil. If formed of the very productive wind-deposited material called loess, there is an advantage in making this appear in the name rather than merely to term it a silt loam. So also the pebbly clay loams and pebbly sandy loam of the glacial deposits may have one degree of productiveness in a level till plain and quite another in a hilly moraine. It is for this reason that pains have been taken in the legend of the map to set forth the geologic as well as the soil names. Another reason for this mapping and description is that the method of the work is genetic rather than analytic. It deals with the origin of the formations in larger divisions rather than with the physical conditions section by section and area by area. It is not sufficiently detailed to justify the purchase or sale of the land from an examination of the map alone. It gives, however, an accurate general classification of the land and its surroundings.

The field work of this report on Minnesota was begun in 1906. The writer has devoted to this work a considerable part of each field season to 1914, except 1908. Field assistance has been rendered four seasons

by Frederick W. Sardeson as geologist, and one season each by Rollin T. Chamberlin and Earl R. Preston as field assistants. Arthur H. Elftman furnished valuable information and accompanied the writer for a brief period in 1913 into the wild portion of the State with which he was especially familiar from work on an earlier State Survey. Field conferences have been held also with members of the United States Bureau of Soils and of the State Department of Agriculture. The map and report on Pennington County and part of Polk County here presented is based largely upon the work of the Bureau of Soils. In the preparation of this report much aid has been derived from the monograph on the glacial Lake Agassiz by Warren Upham and from the reports of counties in the Final Reports of the Geological and Natural History Survey of Minnesota. Free use has been made also of the reports and maps of the State Drainage Commission.

CHAPTER I

TOPOGRAPHY OF MINNESOTA

GENERAL FEATURES OF THE DRIFT

Minnesota presents more variety in surface features than most of the North Central states, though a great part of it has a level or gently undulating surface. The flattest portion falls largely in the northwest quarter of the State and was once the bed of a great lake known as glacial Lake Agassiz, held in on the north by a sheet of ice or great glacier. The roughest portion is in the northeast quarter which is traversed by volcanic formations and adjacent iron-bearing ranges. In the southeast part along the borders of the Mississippi River there are tributary valleys from 300 to 600 feet deep cut in horizontal beds of sandstone and limestone of that district. There is an elevated area in the southwest part rising in places to over 1,900 feet above sea level, but it has a relatively smooth surface because the inequalities of the rock surface are concealed under a great deposit of drift. The interior of the State has features due entirely to the ice, or great glacier, and its melting waters. It comprises a complex system of undulating to hilly moraines, sandy outwash plains, and clayey till plains, whose extent and distribution bear definite relation to the melting of glaciers that overspread the region.

At and beneath the border of the ice, systems of interlocking ridges and knolls with inclosed basins and lakes, were formed at certain definite lines where the edge of the ice held its position for a relatively long time. These systems are the moraines. The ice border, after long holding its position at one of these moraines, would recede somewhat rapidly to another position and there halt long enough to build up another moraine and so on step by step until the ice had disappeared from the State. On the outer border of a moraine there is often a plain of sandy gravel spread out as an outwash by waters escaping from the ice. On the inner border there is usually a clayey plain known as till plain which was ice-covered during the development of the moraine.

Large areas were covered by lakes as the ice was melting away, and thus much of the drift has been lake-washed and rendered somewhat smoother than the unmodified glacial deposits. Many of these lakes have disappeared because their shallow basins have been filled up.

ALTITUDE

In Minnesota altitudes range from 602 feet, the level of Lake Superior, up to 2,230 feet on high knolls in western Cook County. The

altitude is only 620 feet where the Mississippi River leaves the southeast corner of the State, and is 750 feet along Red River in the northwest corner. The headwaters of the Mississippi and the Leaf Hills farther south reach 1,750 feet. The average altitude of the State is not far from 1,200 feet and a large part of it stands between 1,000 and 1,500 feet. A narrow area below 1,000 feet covers the Red River Valley and extends from it into the Minnesota Valley and expands to considerable width in the eastern part of the State. There is another narrow strip below 1,000 feet on the border of Lake Superior. The chief areas above 1,500 feet are found in the rocky ranges of the northeast part, in the high tract from the head of the Mississippi to the Leaf Hills in the western part, and in the plateau southwestward from Coteau des Prairies in the southwest part. Only a few square miles in the northeast part rise above 2,000 feet.

RELIEF

The most conspicuous relief is found in the "Sawtooth Range" and other prominent ridges that closely border Lake Superior and which rise abruptly from 500 to 900 feet above the lake. The rock ranges lying back from the shore, though more elevated than those fronting on the lake, seldom rise more than from 200 to 300 feet above the swamps and lakes among them. In fact several of the lakes of Cook County are above 1,900 feet or within 300 feet of the level of the highest points in the State. The most prominent part of the Mesabi Iron Range in St. Louis County rises from 400 to 450 feet above bordering plains. The Coteau des Prairies rises about 700 feet above the plain northeast of its border, but in Minnesota the rise is usually spread over a space of from 12 to 15 miles or more in width, so that the elevation can scarcely be appreciated by one crossing over it. There is a rather rapid rise of from 300 to 500 feet to the sharp range of hills in Ottertail and Becker counties from the Red River Valley. This rise is of especial interest since it seems to have some influence on the rainfall, the precipitation being greater in these hills where air currents are forced upward and cooled than in the bordering lower lands to the north, west, and south.

DRAINAGE

The drainage of Minnesota is widely divergent, part of it leading to the Gulf of Mexico, part to the Gulf of St. Lawrence, and part to Hudson Bay. The Gulf of Mexico receives about 57 per cent, the St. Lawrence less than 9 per cent, and Hudson Bay fully 34 per cent of the drainage. There was a time, however, after the glacial ice had melted from Minnesota but was still occupying the northeast part of the

Superior Basin and neighboring parts of Ontario and Manitoba, when all the drainage was southward to the Gulf of Mexico. The western Superior Basin then overflowed into the St. Croix River, while the Red River Drainage Basin, largely covered by Lake Agassiz, drained southward through Lakes Traverse and Bigstone into the Minnesota Valley.

The drainage to the south, or Gulf of Mexico, has generally a gentle descent, and waterfalls are rather rare, though the Mississippi has notable falls at Minneapolis and there are one or more falls or rapids on several of the tributaries. The drainage to Lake Superior is generally rapid and nearly every stream has several cascades. There is, however, a wide area of the upper St. Louis Basin in which that stream and its tributaries have relatively gentle descent for many miles. The Hudson Bay Drainage has a few rapids and waterfalls in the headwater part of Rainy River and its tributaries, but Red River and its main Minnesota affluent Red Lake River have no falls since no outcrops of solid rock occur along them. There is, however, very rapid descent for a few miles along Red Lake River and its tributary Clearwater River in Red Lake County. Red River is subject to great freshets because its lower course often remains frozen after the southern or headwater part has broken up. Thus ice jams are formed which divert the waters from the channel over the bordering plain.

LAKES

Throughout much of Minnesota, except the northwest, southwest, and southeast corners, small lakes are a common feature. They usually occupy basins among the moraine ridges and knolls and on the outwash plains, but occur to some extent also on the till plains and among rock knobs. The combined area of the lakes within the State is estimated to be about 5,650 square miles, or nearly 7 per cent of the entire area. The largest lake is Red Lake, a very shallow body of water with an area of 440 square miles. Other large lakes are Mille Lacs, also very shallow, Leech, Winnibigoshish, and Minnetonka. Minnetonka and the southern part of Leech Lake extend into a network of deep depressions among morainic ridges, but the other lakes are largely in plains that are slightly below the neighboring districts, partly morainic and partly plain.

CHAPTER II

CLIMATIC CONDITIONS OF MINNESOTA

By U. G. Purssell
Director of the Minnesota Section of the United States Weather Bureau

INTRODUCTION

The agriculture of any region is controlled by its climate. In some parts of the world temperature is the main factor in determining the limits of growth of certain kinds of crops; in others it is rainfall, and in still others it is the amount of sunshine. All of these factors are important in influencing the crop yield even in districts where the general climatic conditions are satisfactory for the growth of plants. In Minnesota these elements are so favorable that a majority of the crops common to the temperate zone may be successfully grown, and a failure of all the important crops is very rare even over a small portion of the State.

Rainfall is an important factor for most crops in the State, because the proper amount of water in the soil at the critical period of development of the plant is necessary to produce a large crop. The length of the growing season also is important and probably no other factor in the study of climate from the standpoint of the agriculturist should be given more consideration. This is the key to an actual knowledge as to the possibilities of success or failure in the production of crops since in parts of the State crops are menaced by frost at some period of their growth, whereas sunshine and moisture seldom vary in Minnesota beyond safe limits.

The State extends from the northern boundary of Iowa, latitude 43° 30′, some 400 miles northward to the farthest point north in the United States, which is 22.85 miles beyond the 49th parallel in the projection to the northwest point of the Lake of the Woods. The greatest width east and west is 367 miles.

The factors which determine the climate of any area are the relative distribution of land and water, the topography of the land surface, and the situation of the area in question with relation to the general movement of the cyclones and anti-cyclones.

The position of Minnesota at the center of North America gives it a climate that is largely continental. In continental climates the temperature extremes are greater and the humidity and rainfall generally less than at places near large bodies of water, such as border on the Atlantic, Pacific, and Gulf coasts of the United States. The effect of

A. PLOWING FOR SEEDING ON A CLAY PLAIN IN BED OF LAKE AGASSIZ

B. HARVESTING CROP ON A CLAY PLAIN IN BED OF LAKE AGASSIZ

winds from great bodies of water is to equalize temperatures of lands near by and to lengthen materially the crop-growing season. This is particularly true of the country in the vicinity of Lake Superior, where the influence of that great inland sea in modifying the cold anti-cyclones gives to that section a more equable climate than would otherwise obtain in that portion of the State. The summer temperatures are likewise modified and people from long distances inland in steadily increasing numbers are establishing summer homes about the lake, to which they are attracted during the hot summer months. There are more than 7,000 small lakes scattered throughout the State and these have a material local influence in modifying the heat of summer and give comfort to thousands of residents on their shores.

Monthly and annual reports of temperature, rainfall, snowfall, etc., have been published for a large number of regular and coöperative stations in Minnesota since 1895. Recently three special section reports have been issued by the United States Weather Bureau giving monthly and annual precipitation totals for all points in the State with a record of ten years or over, together with average temperatures and other data. In these reports the more important facts from all portions of the State are tabulated and the comparative climatic conditions of the different sections graphically shown.

GENERAL CLIMATIC CONDITIONS

Minnesota is in the path of a large proportion of the low-pressure areas which move across the United States from west to east. These areas move at an average speed of 600 miles in twenty-four hours and are preceded by southerly winds and higher temperature and followed by northerly winds and lower temperature. They are usually accompanied by cloudy weather and precipitation; each storm causing an average of from one to two rainy days as it crosses the State.

As there is an average of almost two of these storms each week with fair weather periods between, it follows that the changes in weather conditions are rather rapid. One or two days of stormy weather preceded by fair weather and followed by clearing and lower temperatures to be repeated in turn, make up the usual routine for the week. However, Minnesota is so far from the coast that damaging ocean storms lose much of their severity before reaching its borders.

The northwestern cold waves pass across the State and send their health-giving winds into all parts, and yet they are frequently not so severe as they are in some of the plains states in the same latitude or even farther south.

Temperature.—The average annual temperature of Minnesota for the

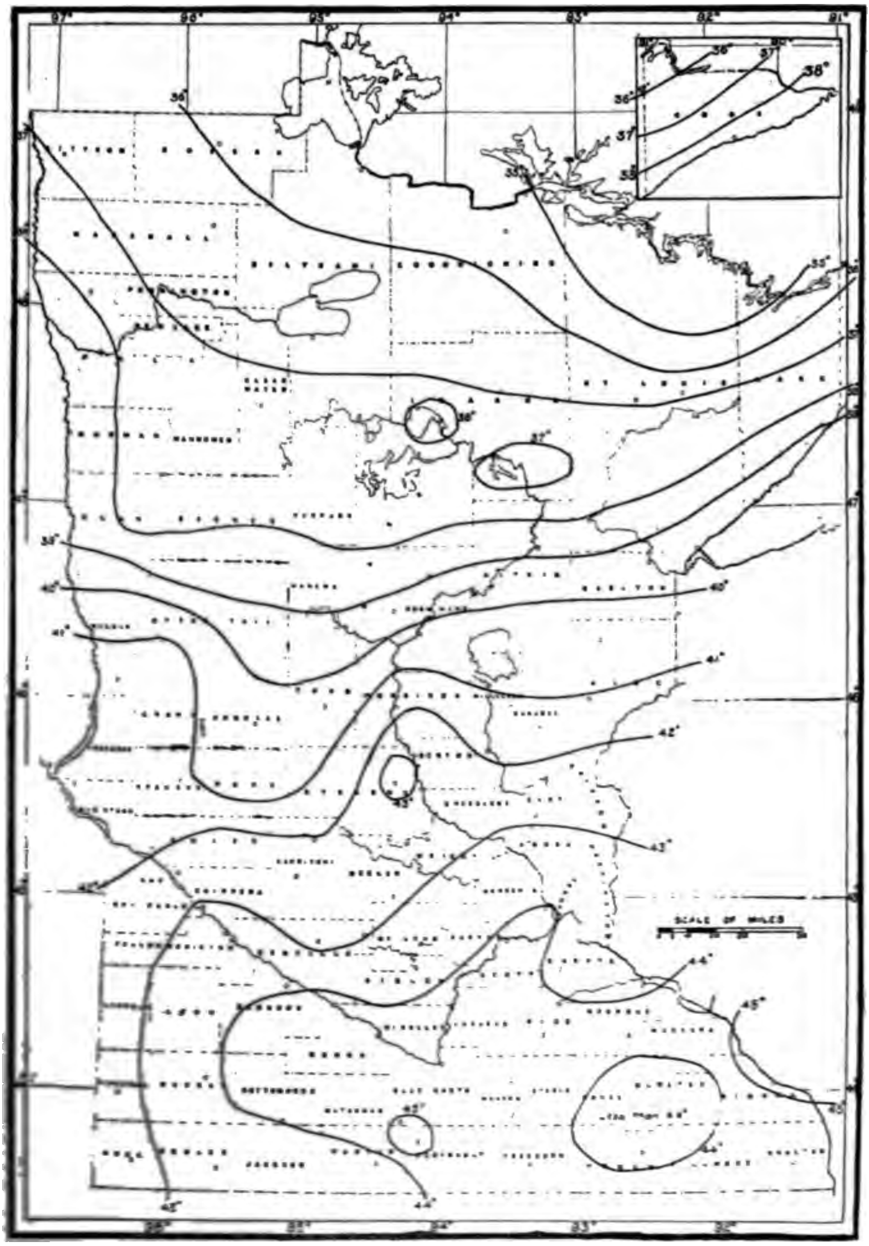

FIGURE 1. MAP SHOWING MEAN ANNUAL TEMPERATURES OF MINNESOTA (DEGREES FAHRENHEIT)

period 1895 to 1913 inclusive, is 41.7°, as shown in Table I and graphically by Figure 1. The highest annual mean temperature, 43.9°, occurred in 1900, and the lowest, 39.9°, in 1912. The departure of the average temperature of any year from the normal may readily be determined by comparing the yearly average with the mean at the foot of the column.

Table I. Monthly and Annual Mean Temperature for Minnesota (Degrees Fahrenheit)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1895	......	......	......	49.9	56.9	64.6	67.8	67.4	61.5	41.4	27.8	18.3	......
1896	12.3	17.9	21.4	44.5	60.9	66.5	69.9	67.9	54.3	42.4	18.0	20.3	41.6
1897	7.2	15.3	20.7	43.7	55.2	62.5	71.6	64.2	65.3	50.0	26.6	12.3	41.2
1898	18.3	16.4	30.3	43.5	55.6	67.0	69.8	66.9	60.6	42.9	26.6	11.9	42.2
1899	9.9	4.5	14.7	44.0	55.1	65.4	70.2	69.1	56.4	49.0	39.6	17.9	41.2
1900	18.4	5.2	23.4	49.5	59.9	66.8	68.8	74.3	58.2	55.1	25.4	18.6	43.9
1901	13.2	10.0	27.3	46.7	58.2	65.5	74.7	69.8	57.3	49.2	28.8	13.0	42.8
1902	15.9	15.5	34.0	42.6	57.0	61.3	69.7	65.2	55.2	47.1	33.3	12.6	42.6
1903	11.3	10.6	29.6	43.3	55.7	62.3	67.2	63.6	55.5	46.1	27.3	9.8	40.3
1904	4.5	2.3	24.8	38.8	55.4	63.2	66.0	64.9	57.4	47.4	36.7	16.7	40.1
1905	5.6	8.9	33.7	42.0	52.6	63.0	67.3	68.9	61.9	43.5	33.1	20.6	41.5
1906	17.0	13.8	20.6	47.9	53.7	63.7	68.3	68.7	63.3	45.7	30.7	15.9	42.0
1907	3.8	14.8	28.7	34.7	45.5	63.3	68.2	66.1	55.9	45.4	31.7	21.3	40.1
1908	16.4	17.9	26.4	45.2	53.9	62.5	69.4	65.5	64.2	47.0	33.8	17.5	43.4
1909	10.5	13.7	26.1	35.8	53.2	65.0	69.2	70.9	58.7	44.7	33.8	10.0	41.0
1910	11.8	7.5	41.7	48.0	51.6	67.8	70.6	65.8	58.4	50.8	25.3	14.7	42.8
1911	5.4	16.6	32.7	42.7	59.8	69.7	68.2	64.0	56.7	43.4	20.2	19.4	41.6
1912	—6.7	10.6	19.8	45.5	55.9	62.5	68.5	63.9	57.2	47.5	33.9	20.0	39.9
1913	7.2	8.6	20.4	46.4	52.7	67.4	67.3	69.2	58.6	42.7	36.9	26.1	42.0
1914	16.9	2.8	26.6	41.2	57.6	64.6	72.4	66.1	60.0	52.6	33.0	......	......
Mean	10.5	11.2	26.5	43.8	55.3	64.7	69.3	67.1	58.8	46.5	30.1	16.7	41.7

The coldest month is January, which has a mean temperature of 10.5°, although the average for February is only 0.7° higher. In a great many instances February has averaged colder than the preceding January. This condition occurred in the seven successive years from 1898 to 1904 inclusive. Average January temperatures are plotted on Figure 2.

July is the warmest month, with an average temperature of 69.1°, although in a few years the mean temperature for June or for August is higher than for July of the same year. Average July temperatures are plotted on Figure 3.

The highest summer mean, 70.0°, occurred in 1900 and 1901. The coldest summer was that of 1903, with an average of 64.4°.

The warmest crop-growing season (April to September inclusive) of the eighteen years under discussion was in 1900, when the average was 62.9°, and the coldest was in 1907, with an average of 55.6°.

The warmest winter (December to February inclusive) was in 1907-8, when the mean temperature was 18.5°. The coldest was in 1903-4, with a mean temperature of 5.5°. Table II shows also the warmest and coldest spring and autumn.

In Figures 4 and 5 are shown the highest and lowest temperatures ever recorded in the various counties where records have been kept.

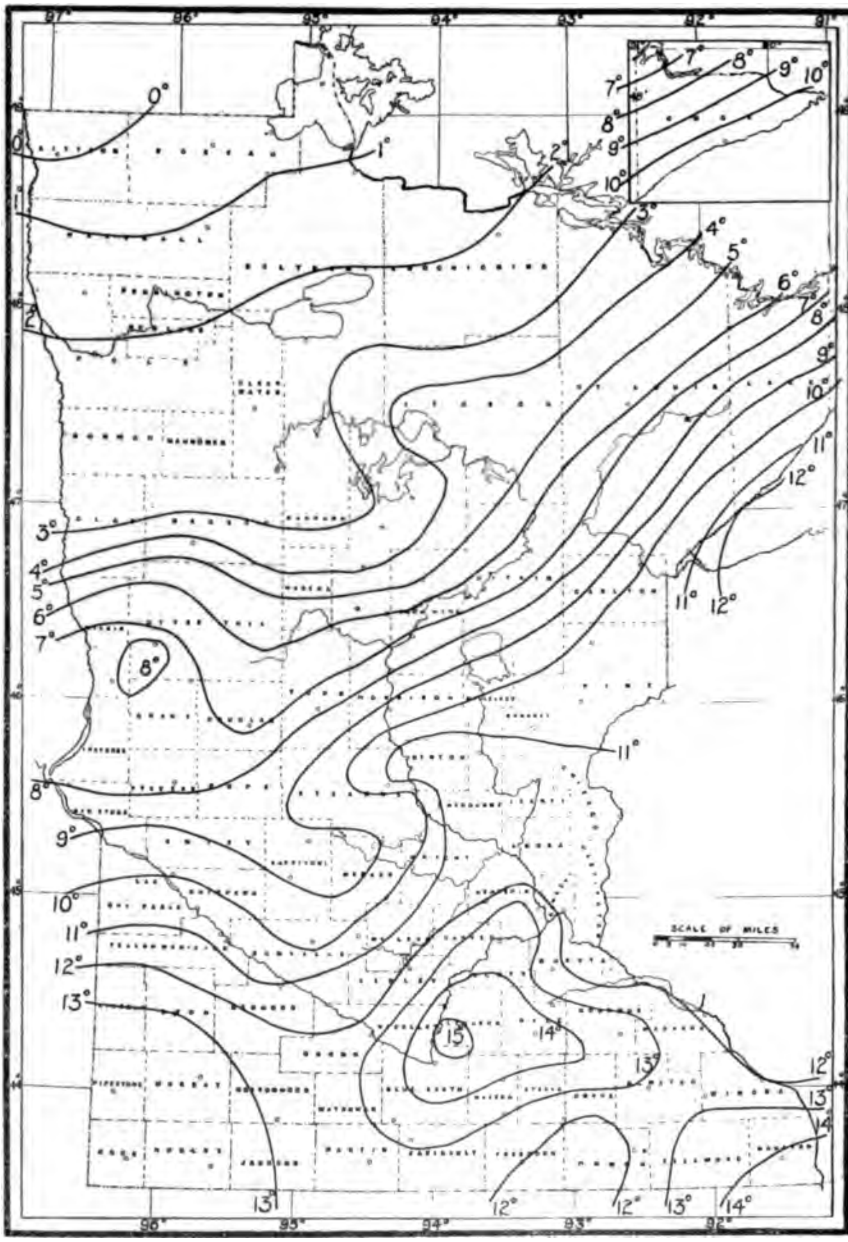

FIGURE 2. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JANUARY (DEGREES FAHRENHEIT)

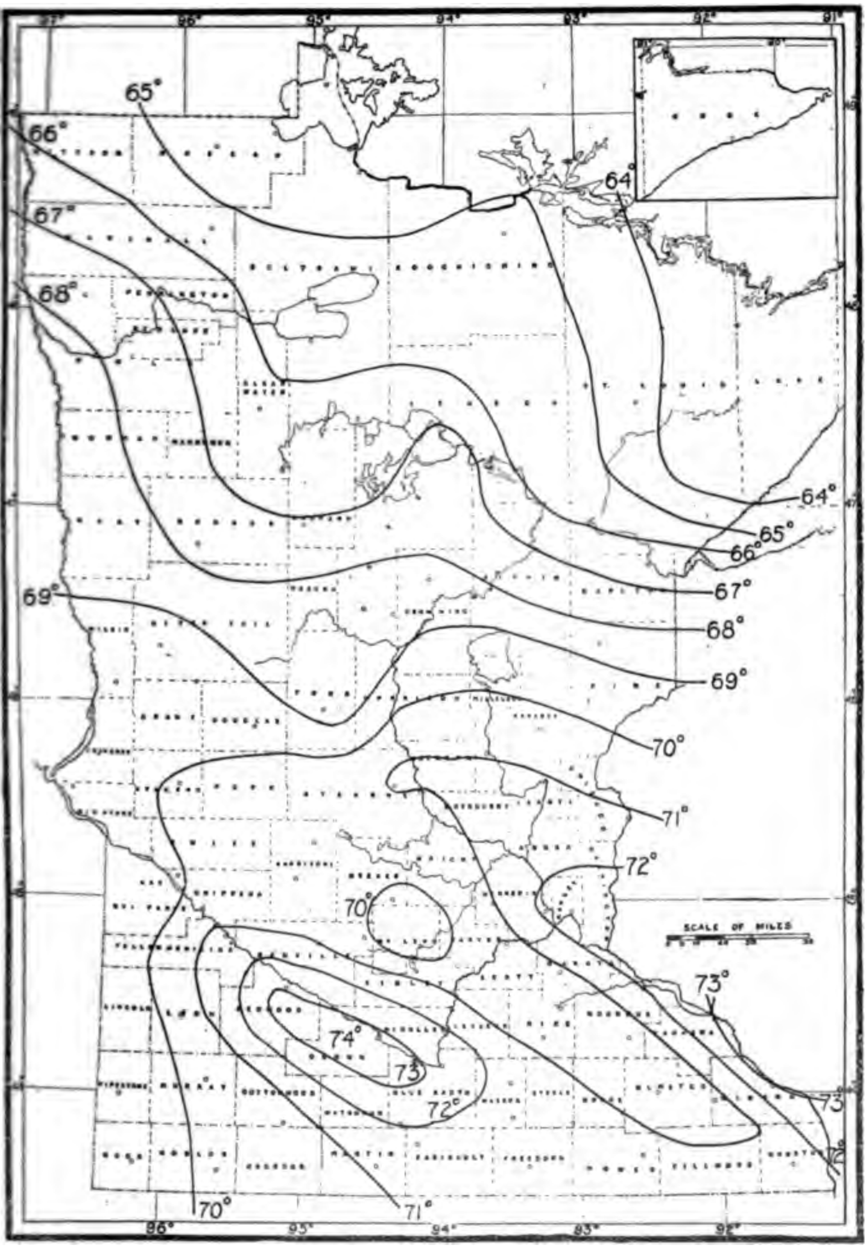

FIGURE 3. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

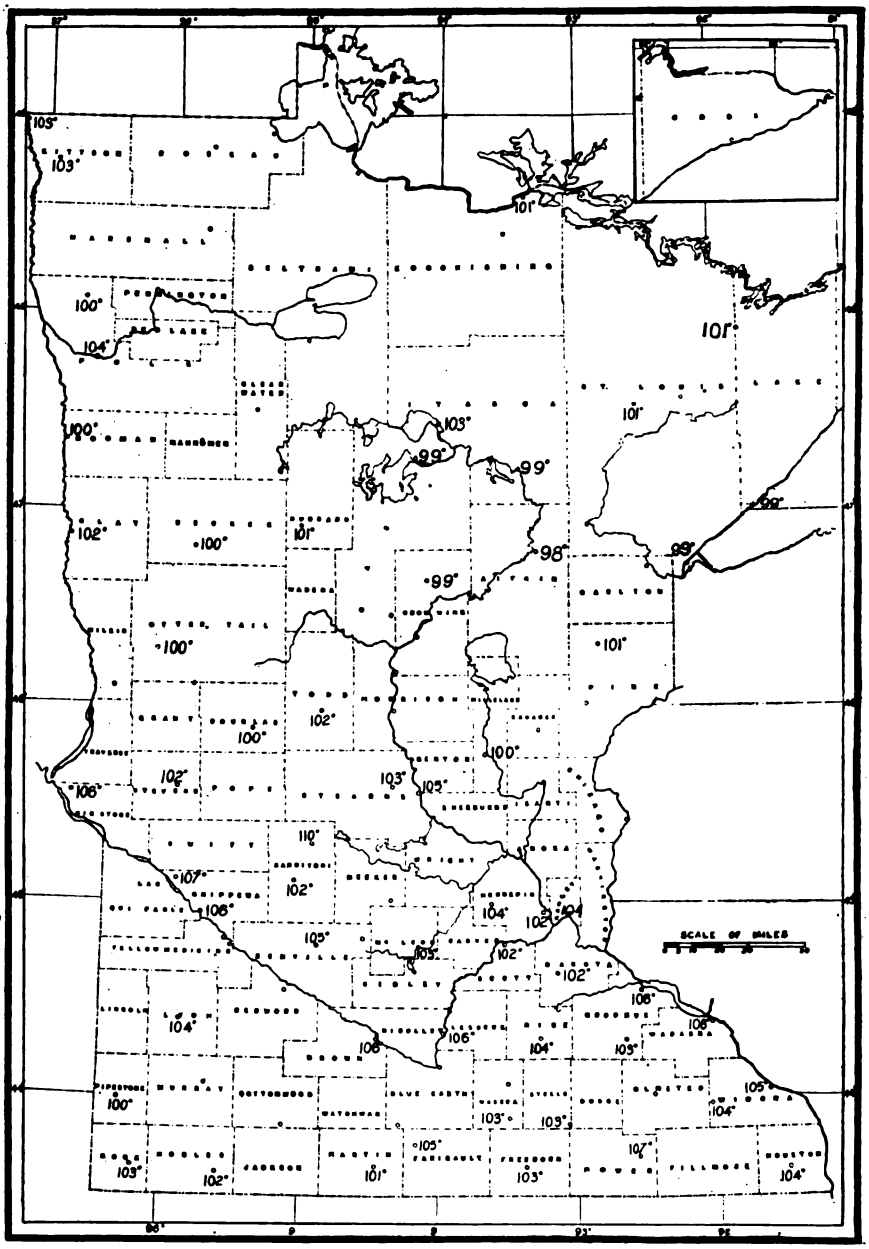

FIGURE 4. MAP SHOWING HIGHEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

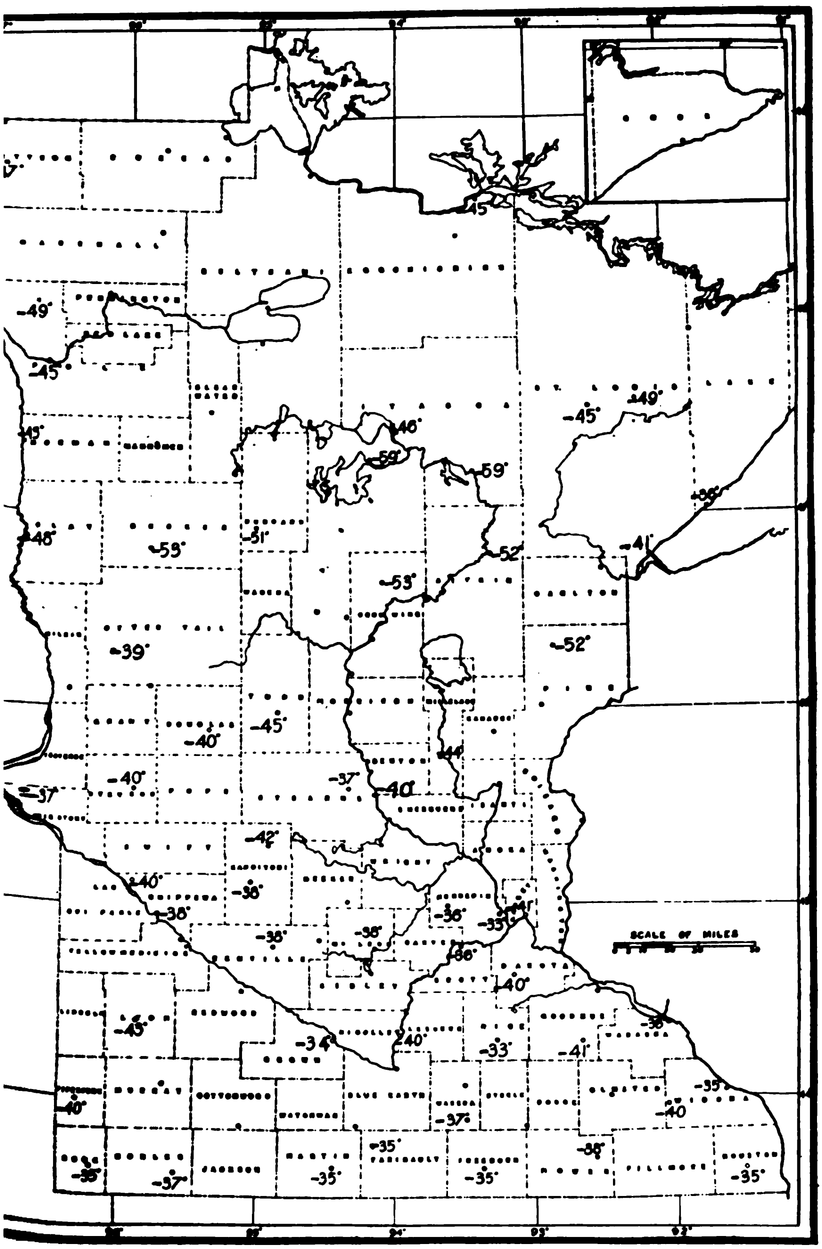

FIGURE 5. MAP SHOWING LOWEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

From these figures it can readily be seen that the extreme range of temperature is from 107° at Grand Meadow and Milan, to —59° at Leech Lake Dam and Pokegama Falls. Temperatures above 100° have been recorded in all counties except those about the headwaters of the Mississippi River, and in the country immediately bordering on Lake Superior. Temperatures of —40° have occurred in nearly all northern and central counties and in a few southern counties, but these great extremes do not occur frequently.

Table II. Seasonal Temperatures for Minnesota (Degrees Fahrenheit)

Year	Winter mean	Spring mean	Summer mean	Fall mean	April to Sept. inclusive (crop-growing season)
1895	....	....	....	....	61.4
1896	16.2	42.3	68.1	38.2	60.7
1897	14.3	39.9	66.1	47.3	60.4
1898	15.7	43.1	67.9	43.4	60.6
1899	8.8	37.9	68.2	48.3	60.0
1900	13.8	44.3	70.0	46.2	62.9
1901	13.9	44.1	70.0	45.1	62.0
1902	14.8	44.5	65.4	45.2	58.5
1903	11.5	42.9	64.4	43.0	57.9
1904	5.5	40.0	64.7	47.2	57.6
1905	10.4	42.8	66.4	46.2	59.3
1906	17.1	40.7	66.9	46.6	60.9
1907	11.5	36.3	65.9	44.3	55.6
1908	18.5	41.8	65.8	48.3	60.1
1909	13.9	38.4	68.4	45.7	58.8
1910	9.8	47.1	68.1	44.8	60.4
1911	12.2	45.1	67.3	40.1	60.2
1912	7.8	40.4	65.0	46.2	58.9
1913	11.9	39.8	68.0	46.1	60.3
1914	15.3	41.8	67.7	48.5	60.3
Mean	12.8	41.7	67.0	45.3	59.8

Frosts.—Although frosts have occurred in some portions of the State every month of the year, damaging temperatures are not to be expected during June, July, and August, and they are comparatively rare in the last half of May and the first half of September. Records of ten or more years are available from a large number of places in the State, of which charts have been constructed showing the average date of the last killing frost in spring and the first one in autumn. Using these dates as boundaries, we can mark the average beginning and ending of crop growth and determine the average length of the growing season. All of this information is graphically shown in Figures 6, 7, and 8. By reference to Figure 8 the influence of Lake Superior in lengthening the crop-growing season in its vicinity may be seen; while in the same latitude in the highlands of Hubbard, Becker, eastern Mahnomen, and Clearwater counties the season is twenty to thirty days shorter. The longest season, 160 days, obtains along the Mississippi River from Hennepin County to the southeastern corner of the State, and the shortest, 100 days or less, is in the region of the Mesabi and Vermilion Iron Ranges.

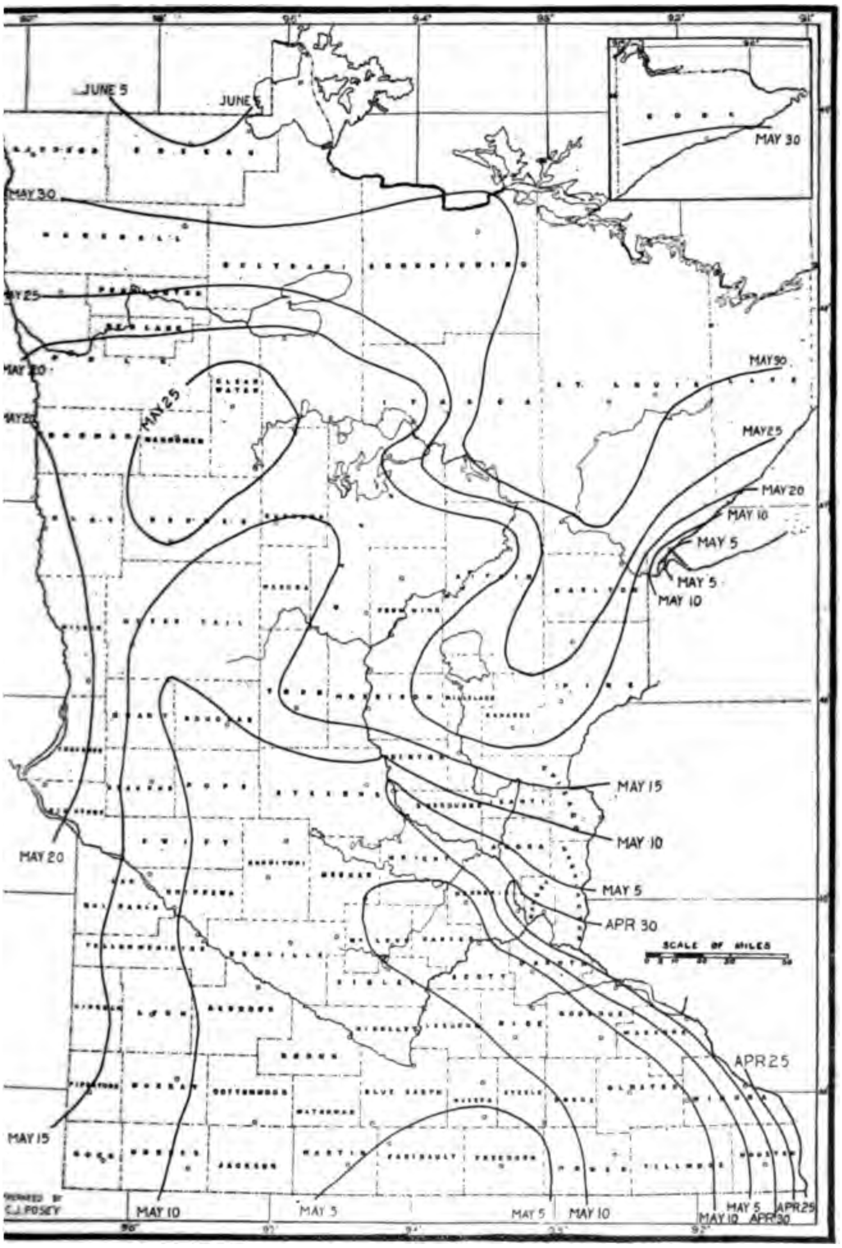

FIGURE 6. MAP SHOWING AVERAGE DATE OF THE LAST KILLING FROST IN SPRING IN MINNESOTA

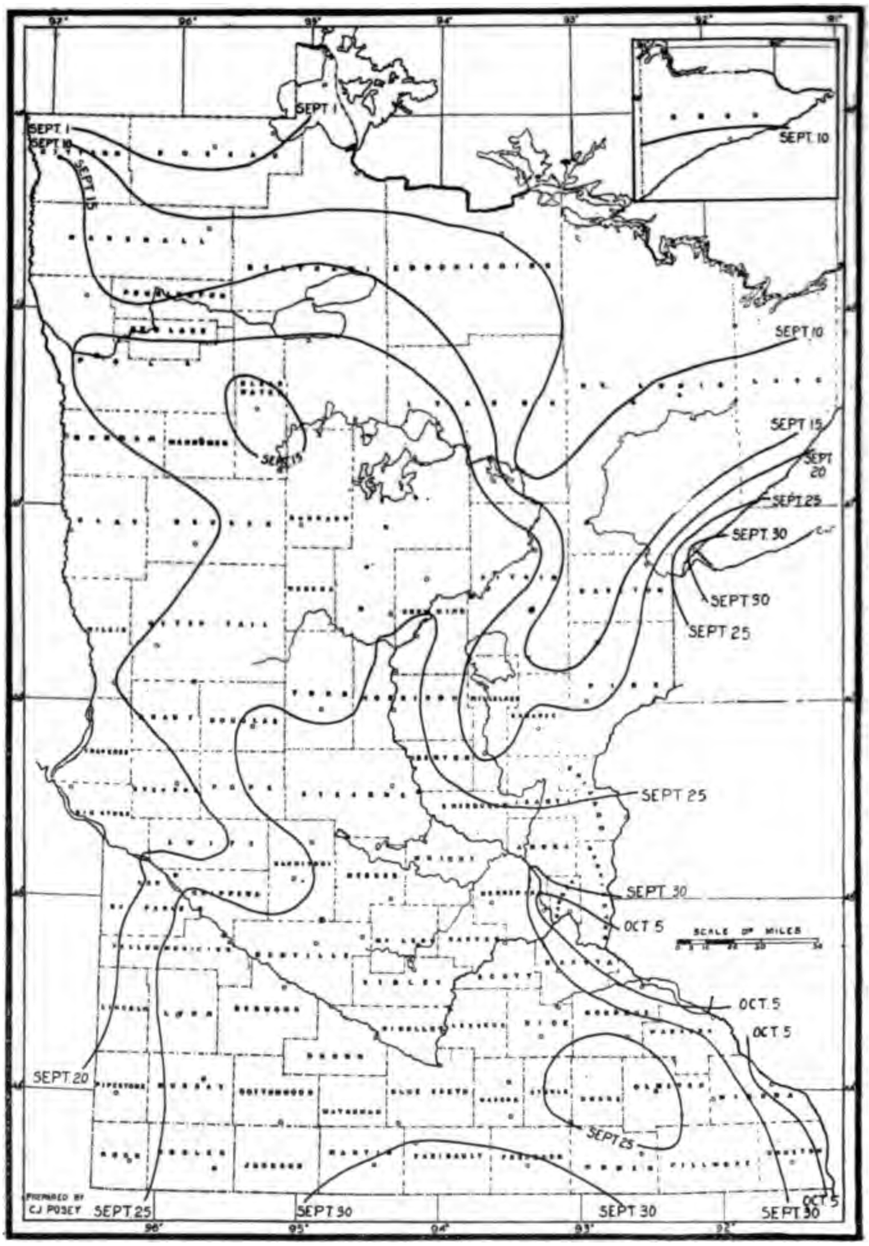

FIGURE 7. MAP SHOWING AVERAGE DATE OF FIRST KILLING FROST IN AUTUMN IN MINNESOTA

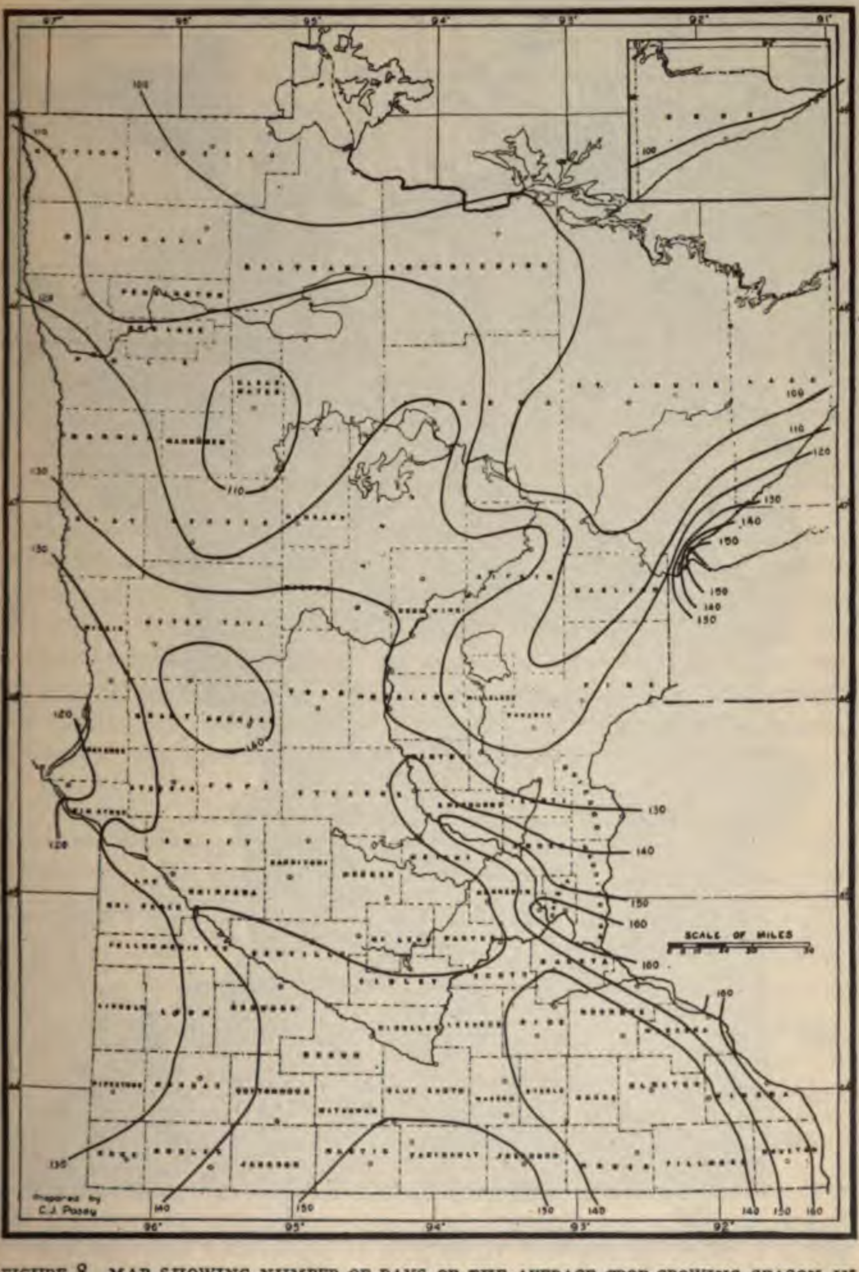

FIGURE 8. MAP SHOWING NUMBER OF DAYS OF THE AVERAGE CROP-GROWING SEASON IN MINNESOTA

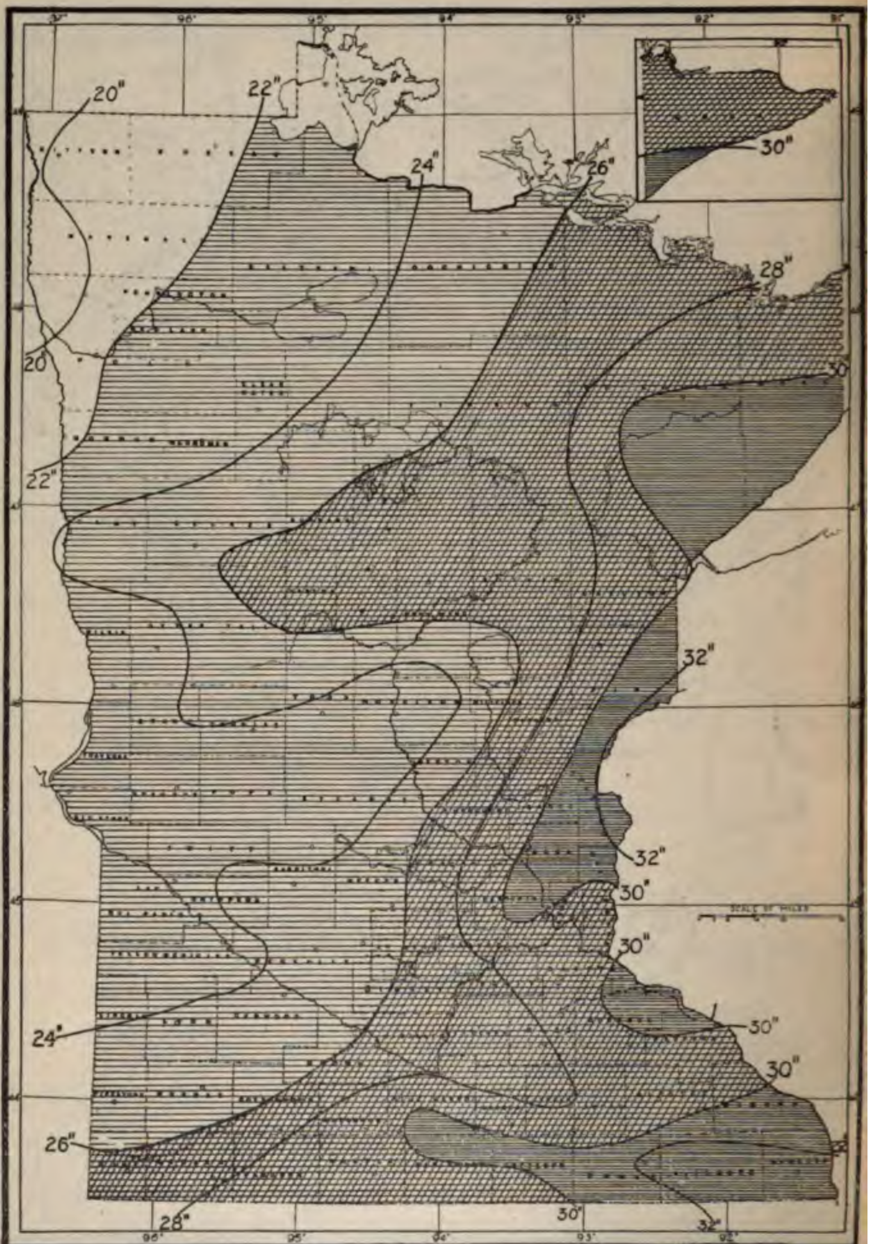

FIGURE 9. MAP SHOWING THE AVERAGE ANNUAL PRECIPITATION FOR MINNESOTA

Table III. Average Monthly and Annual Precipitation for Minnesota (in Inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Total April to Sept. incl.
1895....	......	......	......	1.68	3.30	4.37	3.25	2.27	3.93	0.25	1.22	0.28	......	18.80
1896....	0.76	0.39	1.97	5.91	5.02	4.07	1.88	2.28	2.49	2.95	2.69	0.61	32.04	21.65
1897....	1.77	1.21	2.07	1.55	1.38	5.40	6.62	2.54	1.89	1.55	0.53	0.38	27.23	19.38
1898....	0.16	1.02	1.21	1.64	3.26	3.93	2.94	3.22	1.52	3.83	1.02	0.18	24.21	16.51
1899....	0.60	0.78	1.58	1.49	4.46	6.36	2.84	5.35	1.47	3.22	0.63	0.95	30.14	21.97
1900....	0.48	0.56	1.30	1.47	0.90	1.71	5.48	6.44	6.55	3.85	0.62	0.51	29.79	22.55
1901....	0.38	0.40	1.68	1.73	1.41	5.81	3.33	2.21	4.34	1.86	0.78	0.57	24.26	18.83
1902....	0.44	0.67	0.92	1.67	5.10	3.32	4.76	4.35	2.23	1.93	1.57	1.79	29.46	21.43
1903....	0.45	0.59	1.75	2.82	5.37	1.96	5.11	4.65	5.63	3.13	0.35	0.84	32.85	25.54
1904....	0.39	0.62	1.51	1.72	2.43	4.26	3.96	2.77	3.14	3.50	0.14	0.82	29.65	18.28
1905....	0.65	0.55	1.21	1.46	5.54	6.41	4.12	4.36	3.45	2.53	2.64	0.15	33.10	25.34
1906....	1.15	0.27	1.20	1.72	5.58	4.55	2.93	4.66	3.73	2.28	1.82	0.91	31.66	23.17
1907....	1.17	0.58	0.94	1.01	2.14	4.31	3.57	4.11	3.48	1.31	0.57	0.57	24.03	18.62
1908....	0.31	1.11	1.47	2.55	6.31	6.35	3.21	2.07	2.41	1.91	1.18	0.79	29.49	22.90
1909....	1.32	1.31	0.54	1.89	3.36	3.53	3.84	4.54	3.16	1.56	2.68	1.54	29.27	20.32
1910....	0.83	0.45	0.27	1.54	1.58	1.39	1.94	2.35	2.45	0.97	0.52	0.44	14.73	11.25
1911....	0.81	0.88	0.63	1.88	3.48	3.79	3.61	4.27	3.35	3.93	1.12	1.35	29.10	20.38
1912....	0.40	0.21	0.45	2.04	4.13	1.66	4.30	3.97	3.03	0.97	0.36	0.93	22.45	19.13
1913....	0.33	0.44	1.27	1.87	3.53	3.08	5.56	2.79	3.33	2.58	0.66	0.05	25.49	20.16
1914....	0.81	0.44	1.12	2.41	2.89	8.34	2.48	3.97	3.08	2.00	0.38	......	......	23.77
Mean..	0.70	0.66	1.22	2.00	3.56	4.18	3.79	3.66	3.23	2.31	1.07	0.71	27.72	20.33

Precipitation.—The annual average precipitation of the State as a whole for a period of eighteen years, 1896 to 1913 inclusive, is *27.72* inches, and for the crop season, April to September inclusive, for nineteen years, 1895 to 1913, is 20.16 inches. The monthly, seasonal, and annual averages for this period are shown in Table III. The year with the greatest annual rainfall was 1905, when the total was 33.10 inches. The driest year was 1910 with 14.73 inches. In that year the rainfall during the crop-growing season was 11.25 inches.

Table IV. Average Monthly and Annual Precipitation by Drainage Districts

Watersheds	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake Superior...	0.88	0.88	1.41	2.05	3.50	4.19	4.21	3.73	4.18	2.80	1.45	1.13	30.40
Rainy River.....	0.94	0.94	1.42	1.96	3.10	4.04	3.76	3.32	2.98	2.08	1.46	0.98	26.98
Red River.......	0.55	0.56	0.98	1.84	2.85	3.83	3.34	3.12	2.32	1.55	0.72	0.56	22.22
Mississippi (above St. Croix)......	0.73	0.70	1.23	2.16	3.42	4.13	3.61	3.57	3.00	2.29	1.05	0.73	26.63
St. Croix and Mississippi (below St. Croix).....	0.92	0.95	1.49	2.37	4.01	4.46	3.72	3.69	3.72	2.73	1.36	1.13	30.57
Minnesota River.	0.79	0.73	1.19	2.30	3.52	4.18	3.34	3.44	2.63	2.11	1.02	0.79	26.04
Big Sioux and Des Moines Rivers.	0.50	0.54	1.13	2.09	4.00	4.39	3.49	3.58	2.79	2.07	0.94	0.63	26.15
State.......	0.76	0.75	1.25	2.18	3.53	4.19	3.55	3.50	3.02	2.24	1.09	0.84	26.90

June is the wettest month with an average rainfall of 4.18 inches, and July is next with 3.79 inches. The lowest monthly rainfall is that of February with an average of 0.66 inch. The greatest rainfall in one month for the State as a whole was 8.34 inches in June, 1914. The lowest rainfall for any month was .05 inch in December, 1913.

The geographic distribution of annual and monthly precipitation is

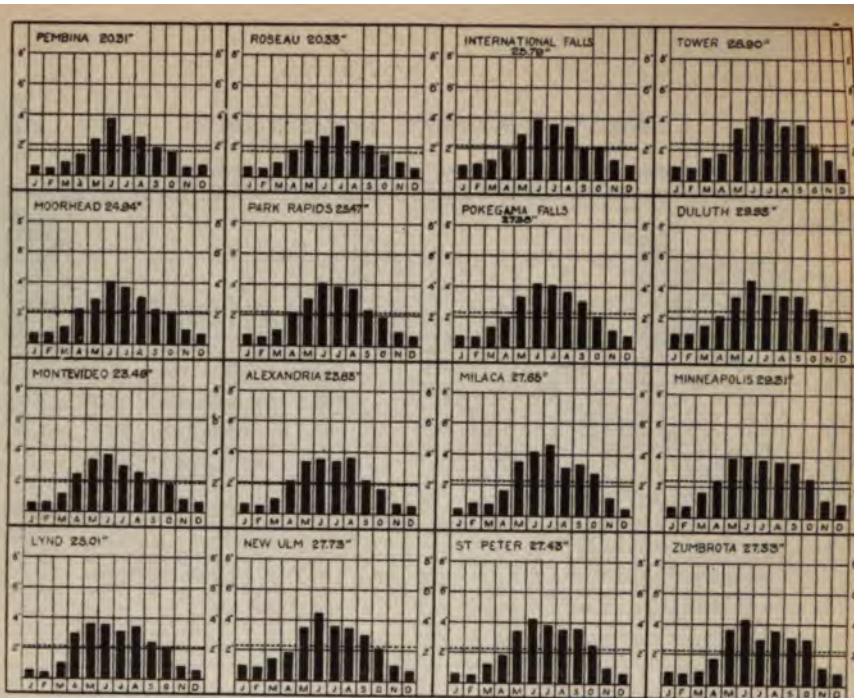

FIGURE 10. DIAGRAM SHOWING COMPARATIVE MONTHLY DISTRIBUTION OF PRECIPITATION IN MINNESOTA. LETTERS INDICATE MONTHS, BLACK COLUMNS INDICATE INCHES OF RAINFALL IN EACH MONTH AT STATION NAMED

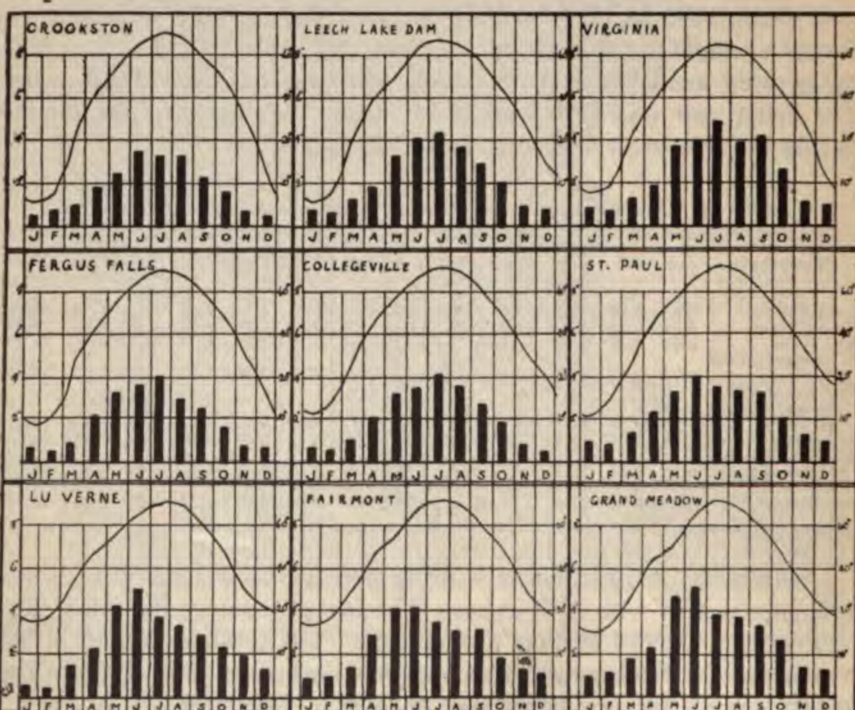

FIGURE 11. MEAN MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURE AT SEVERAL STATIONS IN MINNESOTA. MONTHS ARE INDICATED BY THEIR FIRST LETTERS. THE GREATEST RAINFALL IS IN THE GROWING SEASON

Table VI. Average Snowfall

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Yrs.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake of the Woods Group—														
Tower	9	9.0	8.6	10.9	4.2	0.6	0	0	0	0.2	0.4	8.4	8.2	50.5
Red River Valley Group—														
St. Vincent-Pembina	14	8.4	5.1	6.9	5.2	0.7	0	0	0	0.1	0.7	5.7	6.4	39.2
Crookston	14	6.3	6.7	8.8	3.2	0.2	0	0	0	T.	0.4	4.5	5.7	35.8
Moorhead	17	7.6	6.7	8.9	4.9	0.3	0	0	0	0.1	1.0	6.9	6.8	43.7
Upper Mississippi River Valley Group—														
Park Rapids	14	9.0	6.5	9.1	5.4	0.9	0	0	0	0.2	1.4	7.4	6.3	46.2
Lake Winnibigoshish	14	8.6	6.5	9.9	3.3	0.8	0	0	0	T.	1.0	7.8	7.8	45.7
Sandy Lake Dam	14	9.0	9.5	10.6	3.6	0.7	0	0	0	0.2	1.1	7.4	7.4	49.4
Lake Superior Group—														
Mt. Iron	13	9.9	7.8	11.2	3.9	1.1	0	0	0	0.1	0.8	8.1	11.6	54.4
Duluth	25	10.3	9.1	11.1	4.0	1.0	0	0	0	0.1	0.3	8.2	8.7	52.8
Lower Mississippi River Valley Group—														
La Crosse, Wis.	15	8.4	8.7	6.6	1.4	T.	0	0	0	T.	0.1	3.9	8.9	37.1
Grand Meadow	14	8.0	9.8	9.9	3.1	0.4	0	0	0	T.	0.3	5.3	9.3	46.1
St. Charles	9	7.7	9.4	9.5	2.4	0.2	0	0	0	0	0.1	4.3	9.3	42.9
Red Wing	8	8.0	5.6	4.4	1.8	0.2	0	0	0	T.	0.3	1.5	7.1	28.9
St. Paul	24	7.7	6.2	8.8	3.6	0.2	0	0	0	T.	0.2	4.7	5.7	37.1
Lower Minnesota River Valley Group—														
Shakopee	14	7.7	8.1	7.8	1.9	T.	0	0	0	T.	0.4	3.0	4.6	33.5
St. Peter	13	5.5	6.1	7.1	0.7	T.	0	0	0	0	0.4	1.4	4.0	25.2
Winnebago	10	6.5	7.5	6.3	1.0	T.	0	0	0	T.	0.3	2.3	6.5	30.4
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8.3	8.6	9.5	4.0	0.2	0	0	0	T.	0.3	4.5	6.4	42.4
Collegeville	14	6.7	5.6	8.5	1.8	0.4	0	0	0	T.	0.3	3.5	5.0	31.8
Pine River Dam	14	9.1	8.4	9.5	2.8	0.8	0	0	0	0.1	0.6	5.9	6.8	44.0
Osceola, Wis.	11	9.1	8.4	11.7	2.8	T.	0	0	0	T.	0.1	5.5	6.8	44.4
Grantsburg, Wis.	11	9.2	9.0	12.2	4.2	0.1	0	0	0	0	0.1	8.5	8.9	52.2
Upper Minnesota River Valley Group—														
New Ulm	14	8.9	7.5	9.5	1.7	0.2	0	0	0	T.	0.3	3.5	4.4	36.0
Bird Island	14	4.7	5.8	6.0	1.5	0.4	0	0	0	T.	0.5	3.5	3.4	25.8
Milan	14	7.5	8.1	11.2	1.6	0.5	0	0	0	T.	0.6	4.1	6.1	39.7
Minnesota River Watershed Group—														
New London	14	4.6	4.2	7.0	1.7	0.1	0	0	0	0	0.3	2.7	3.4	24.0
Long Prairie	14	5.7	5.5	7.4	2.4	0.4	0	0	0	T.	0.2	3.3	4.4	29.3
Morris	14	5.2	5.4	7.8	2.1	0.5	0	0	0	0	0.6	3.2	4.4	29.2
Fergus Falls	13	6.2	5.7	7.6	2.8	0.4	0	0	0	T.	1.0	5.7	5.8	35.2
Southwestern Group—														
Fairmont	13	5.0	10.0	8.8	1.9	0.1	0	0	0	T.	0.2	3.9	5.3	35.2
Worthington	13	4.1	7.2	7.6	1.2	T.	0	0	0	0	0.3	2.7	3.6	26.7
Lynd	14	6.3	5.1	7.4	2.8	0.5	0	0	0	T.	1.2	2.8	5.3	31.4
Gary, S. D.	11	4.4	6.6	12.4	4.5	0.2	0	0	0	T.	1.2	4.2	4.1	37.6

83 per cent at 7 a. m. and 72 per cent at 7 p. m. Table IX gives the monthly and annual data.

Number of rainy days.—In Table X the number of rainy days during each month and the year is given for thirty-three stations well distributed over the State. The smallest number is 64 at Lynd, Lyon County, and the largest 132 days at Duluth.

Sunshine.—The sunshine is abundant, averaging from 43 to 53 per cent of the highest amount possible. The daylight hours are materially longer during the crop-growing season in the northern portion of the State than in the southern. The greatest percentage of sunshine is in the southwestern portion and the least in the northeastern part.

graphically shown in Figures 9 to 11, and for the stations having ten or more years of record in Table V. Table IV shows the monthly and annual distribution in the various watersheds. From these illustrations it may be seen that the precipitation is about one-fourth to one-third greater along the eastern boundary of the State than along the western boundary.

Table V. Average Annual Precipitation in Minnesota by Stations

Station	County	Length of record	Average annual precip.	Station	County	Length of record	Average annual precip.
		Yrs.	Inches			Yrs.	Inches
Albert Lea	Freeborn	21	29.90	Montevideo	Chippewa	22	23.50
Alexandria	Douglas	25	23.74	Moorhead	Clay	31	24.9[illegible]
Angus	Polk	10	19.00	Morris	Stevens	27	23.2[illegible]
Ashby	Grant	14	24.47	New London	Kandiyohi	18	23.6[illegible]
Beardsley	Bigstone	16	23.79	New Richland	Waseca	10	29.9[illegible]
Bird Island	Renville	22	24.23	New Ulm	Brown	32	27.7[illegible]
Blooming Prairie	Steele	13	27.45	Northfield	Rice	12	29.9[illegible]
Caledonia	Houston	19	33.70	Osceola, Wis	Polk	21	32.1[illegible]
Collegeville	Stearns	19	22.76	Park Rapids	Hubbard	22	25.7[illegible]
Crookston	Polk	22	22.41	Pembina, N. D	Pembina	14	19.7[illegible]
Detroit	Becker	16	25.96	Pine River Dam	Crow Wing	25	27.5[illegible]
Duluth	St. Louis	41	29.93	Pipestone	Pipestone	12	24.1[illegible]
Fairmont (near)	Martin	25	28.20	Pokegama Falls	Itasca	25	27.6[illegible]
Faribault	Rice	14	28.00	Red Wing	Goodhue	16	31.7[illegible]
Farmington	Dakota	24	29.29	Redwood Falls	Redwood	13	24.6[illegible]
Fergus Falls	Ottertail	24	23.24	Reeds Landing	Wabasha	16	29.3[illegible]
Flandreau, S. D	Moody	22	24.57	St. Charles	Winona	21	30.6[illegible]
Fort Ripley	Crow Wing	43	25.25	St. Cloud	Sherburne	19	27.6[illegible]
Glencoe	McLeod	15	26.64	St. Paul	Ramsey	41	28.6[illegible]
Grand Meadow	Mower	24	32.59	St. Peter	Nicollet	18	27.8[illegible]
Grantsburg, Wis	Burnett	21	33.06	Sandy Lake Dam	Aitkin	19	26.4[illegible]
Hallock	Kittson	13	21.37	Shakopee	Scott	15	28.8[illegible]
Halstad (Ada)	Norman	16	21.27	Tonka	Hennepin	13	30.5[illegible]
International Falls	Koochiching	10	25.75	Tower (Ely)	St. Louis	10	28.1[illegible]
La Crosse, Wis	La Crosse	40	31.17	Two Harbors	Lake	18	30.5[illegible]
Leech Lake Dam	Cass	24	27.00	University, N. D	Grand Forks	20	20.4[illegible]
Long Prairie	Todd	20	25.17	Virginia (Mt. Iron)	St. Louis	18	30.7[illegible]
Luverne	Rock	15	27.60	Wabasha	Wabasha	17	30.5[illegible]
Lynd	Lyon	19	25.43	Wahpeton, N. D	Richland	20	23.6[illegible]
Mankato	Blue Earth	14	27.50	Willmar	Kandiyohi	10	25.54
Mapleplain	Hennepin	17	31.11	Willow River	Pine	10	29.98
Milaca	Mille Lacs	13	27.27	Winnebago	Faribault	14	30.58
Milan	Chippewa	18	24.49	Winnibigoshish	Itasca	25	25.66
Milbank, S. D	Grant	21	22.69	Winona	Winona	16	29.63
Minneapolis	Hennepin	21	29.31	Worthington	Nobles	17	28.24

Figure 11 makes an interesting comparison of monthly and annual values of both temperature and rainfall at certain selected representative stations.

Snowfall.—The snowfall averages from 24 to 54 inches. It is lightest in the southwest portion of the State and heaviest on the Mesabi Iron Range. The monthly and annual averages are shown in Table VI, arranged according to sections and drainage districts.

Winds.—The prevailing winds are from the northwest over most of the State. The monthly and annual prevailing directions are shown for a large group of stations in Table VII. The average hourly wind velocity is shown for six regular Weather Bureau stations and three special stations in Table VIII.

Relative humidity.—The average annual humidity for the State is

A. FLAX FIELD ON RED RIVER CLAY PLAIN

B. POTATO FIELD ON RED RIVER CLAY PLAIN

C. CORN FIELD ON RED RIVER CLAY PLAIN

Table VI. Average Snowfall

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Yrs.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake of the Woods Group—														
Tower	9	9.0	8.6	10.9	4.2	0.6	0	0	0	0.2	0.4	8.4	8.2	50.5
Red River Valley Group—														
St. Vincent-Pembina	14	8.4	5.1	6.9	5.2	0.7	0	0	0	0.1	0.7	5.7	6.4	39.2
Crookston	14	6.3	6.7	8.8	3.2	0.2	0	0	0	T.	0.4	4.5	5.7	35.8
Moorhead	17	7.6	6.7	8.9	4.9	0.3	0	0	0	0.1	1.0	6.9	6.8	43.7
Upper Mississippi River Valley Group—														
Park Rapids	14	9.0	6.5	9.1	5.4	0.9	0	0	0	0.2	1.4	7.4	6.3	46.2
Lake Winnibigoshish	14	8.6	6.5	9.9	3.3	0.8	0	0	0	T.	1.0	7.8	7.8	45.7
Sandy Lake Dam	14	9.0	9.5	10.6	3.6	0.7	0	0	0	0.2	1.1	7.4	7.4	49.4
Lake Superior Group—														
Mt. Iron	13	9.9	7.8	11.2	3.9	1.1	0	0	0	0.1	0.8	8.1	11.6	54.4
Duluth	25	10.3	9.1	11.1	4.0	1.0	0	0	0	0.1	0.3	8.2	8.7	52.8
Lower Mississippi River Valley Group—														
La Crosse, Wis.	15	8.4	8.7	6.6	1.4	T.	0	0	0	T.	0.1	3.9	8.9	37.1
Grand Meadow	14	8.0	9.8	9.9	3.1	0.4	0	0	0	T.	0.3	5.3	9.3	46.1
St. Charles	9	7.7	9.4	9.5	2.4	0.2	0	0	0	0	0.1	4.3	9.3	42.9
Red Wing	8	8.0	5.6	4.4	1.8	0.2	0	0	0	T.	0.3	1.5	7.1	28.9
St. Paul	24	7.7	6.2	8.8	3.6	0.2	0	0	0	T.	0.2	4.7	5.7	37.1
Lower Minnesota River Valley Group—														
Shakopee	14	7.7	8.1	7.8	1.9	T.	0	0	0	T.	0.4	3.0	4.6	33.5
St. Peter	13	5.5	6.1	7.1	0.7	T.	0	0	0	0	0.4	1.4	4.0	25.2
Winnebago	10	6.5	7.5	6.3	1.0	T.	0	0	0	T.	0.3	2.3	6.5	30.4
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8.3	8.6	9.5	4.0	0.2	0	0	0	T.	0.3	4.5	6.4	42.4
Collegeville	14	6.7	5.6	8.5	1.8	0.4	0	0	0	T.	0.3	3.5	5.0	31.8
Pine River Dam	14	9.1	8.4	9.5	2.8	0.8	0	0	0	0.1	0.6	5.9	6.8	44.0
Osceola, Wis.	11	9.1	8.4	11.7	2.8	T.	0	0	0	T.	0.1	5.5	6.8	44.4
Grantsburg, Wis.	11	9.2	9.0	12.2	4.2	0.1	0	0	0	0	0.1	8.5	8.9	52.2
Upper Minnesota River Valley Group—														
New Ulm	14	8.9	7.5	9.5	1.7	0.2	0	0	0	T.	0.3	3.5	4.4	36.0
Bird Island	14	4.7	5.8	6.0	1.5	0.4	0	0	0	T.	0.5	3.5	3.4	25.8
Milan	14	7.5	8.1	11.2	1.6	0.5	0	0	0	T.	0.6	4.1	6.1	39.7
Minnesota River Watershed Group—														
New London	14	4.6	4.2	7.0	1.7	0.1	0	0	0	0	0.3	2.7	3.4	24.0
Long Prairie	14	5.7	5.5	7.4	2.4	0.4	0	0	0	T.	0.2	3.3	4.4	29.3
Morris	14	5.2	5.4	7.8	2.1	0.5	0	0	0	0	0.6	3.2	4.4	29.2
Fergus Falls	13	6.2	5.7	7.6	2.8	0.4	0	0	0	T.	1.0	5.7	5.8	35.2
Southwestern Group—														
Fairmont	13	5.0	10.0	8.8	1.9	0.1	0	0	0	T.	0.2	3.9	5.3	35.2
Worthington	13	4.1	7.2	7.6	1.2	T.	0	0	0	0	0.3	2.7	3.6	26.7
Lynd	14	6.3	5.1	7.4	2.8	0.5	0	0	0	T.	1.2	2.8	5.3	31.4
Gary, S. D.	11	4.4	6.6	12.4	4.5	0.2	0	0	0	T.	1.2	4.2	4.1	37.6

83 per cent at 7 a. m. and 72 per cent at 7 p. m. Table IX gives the monthly and annual data.

Number of rainy days.—In Table X the number of rainy days during each month and the year is given for thirty-three stations well distributed over the State. The smallest number is 64 at Lynd, Lyon County, and the largest 132 days at Duluth.

Sunshine.—The sunshine is abundant, averaging from 43 to 53 per cent of the highest amount possible. The daylight hours are materially longer during the crop-growing season in the northern portion of the State than in the southern. The greatest percentage of sunshine is in the southwestern portion and the least in the northeastern part.

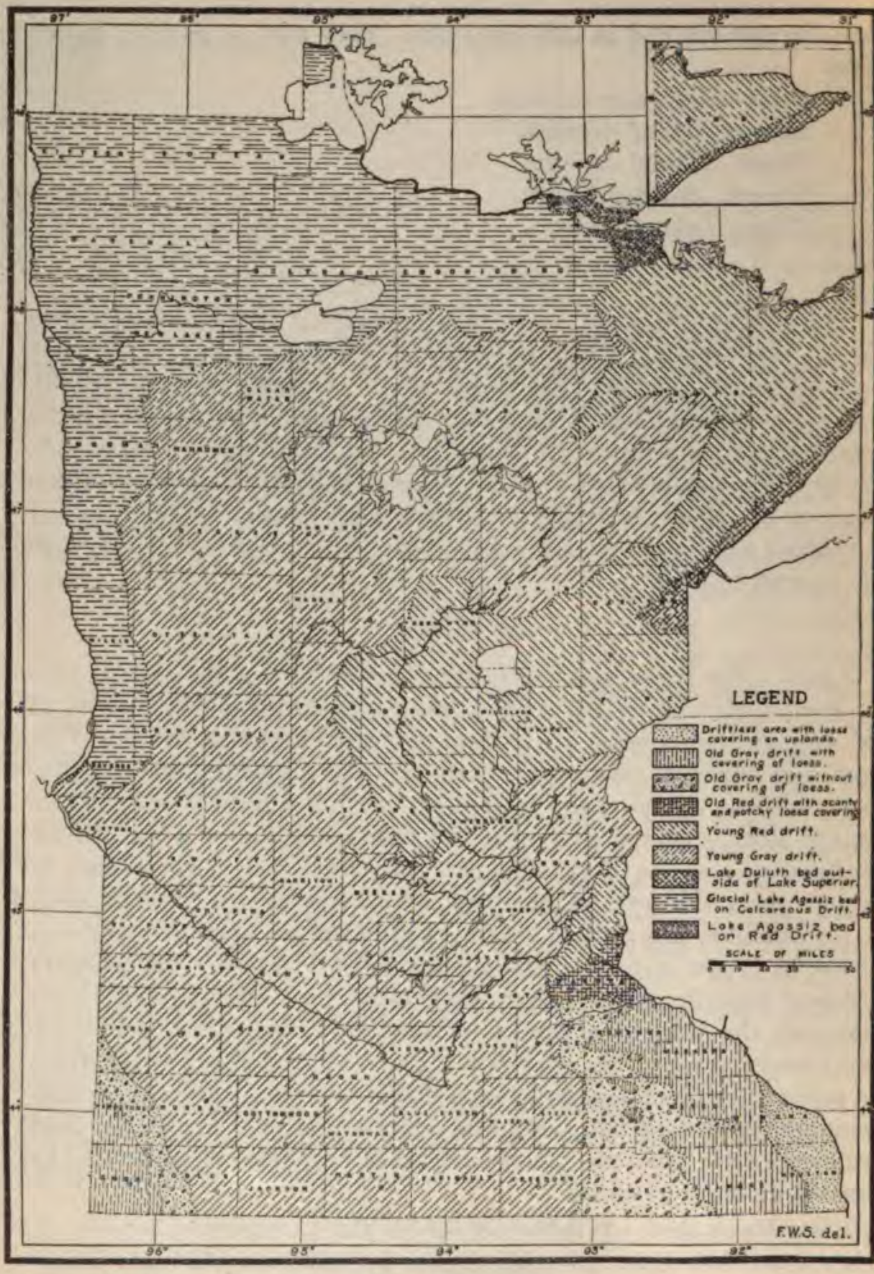

FIGURE 13. MAP SHOWING DISTRIBUTION OF GLACIAL DRIFT LOESS AND GLACIAL LAKES IN MINNESOTA BY FRANK LEVERETT

There is more or less wind-drifted sand in the sandy parts of the St. Louis River Drainage Basin, but it is sparingly developed compared to that in the district between the Mississippi and St. Croix rivers. Wind-blown sand occurs also in Aitkin County in the vicinity of McGregor and also in the northeastern part of the county in island-like tracts that are surrounded by marshes. There are numerous small areas of such sand scattered over the State, some of them being along the shores of the glacial Lake Agassiz.

GLACIAL DEPOSITS

The glacial deposits extend over the entire State except eastern Winona County and the greater part of Houston County, which are in the driftless area of the upper Mississippi. They underlie the wind-deposited sands and much of the loess area. They also underlie stream deposits and lake sediments. The glacial deposits are separable into till or bowlder clay in which stones, clay, and sand are closely commingled, and into sand or gravel beds which show some assorting and bedding by water action. The percentage of stony material varies greatly and the matrix also shows variations from compact clay to loose sand. These variations are to be expected in a deposit that had been formed from the dirt and stones included in an ice sheet. Every observing farmer has probably noted and perhaps speculated upon the cause for these variations in the drift deposits which form the basis for so large a part of the Minnesota soil. The assorted sand and gravel beds are largely due to waters escaping from the melting ice and many of them may be traced up to a moraine which marked the position of the ice border at the time they were laid down. They show a decrease in coarseness in passing away from the edge of the moraine, the coarse material having been dropped close to the edge of the ice and only the fine carried to a great distance outside.

The glacial deposits also show some variations that relate to the kind of rock formations over which the ice passed. Thus, the northeastern portion of the State has a rather stony drift from the volcanic and hard crystalline rocks of that region. This stony material was carried as far south as Dakota County and forms the red drift of eastern and northeastern Minnesota. The western and southern parts of the State have a large amount of clayey drift material with limestone pebbles imbedded. This material was gathered by this ice as it passed across in its southward course from the shales and limestone of southern Manitoba, that greatly dominate there over the granite and other crystalline rocks. These clayey and limy deposits form what is known as the gray drift of Minnesota.

CHAPTER III

SURFACE GEOLOGY

ROCK AREAS

The areas in which rock is so exposed as to render the land untillable are largely in the northeast quarter of the State, or along valleys in the southeast quarter. The northwest quarter is estimated to have less than 10 square miles of bare rock outcrop, and the southwest scarcely 100 square miles. It is doubtful if there is an area of 1,000 square miles in the entire State in which the plow would generally strike into rock ledges. The rock areas thus form a much smaller percentage of the State than the lake areas. The rock areas of the northeast part are chiefly rock bosses standing above the surrounding land, but the beds of the streams that lead directly down to Lake Superior are also usually on rock ledges. Among the rock knobs are some depressions covered only with moss and peaty material, glacial material being wanting, but ordinarily some glacial material is present and nearly all the land has soil enough over the bedrock to support a rich forest growth. Many of the knobs preserve the smooth surface left by the scouring effect of the ice sheet and are nearly destitute of vegetation. But certain others have become disintegrated to a depth of several inches or even to several feet from the surface and are supporting growths of vegetation of considerable density.

The rock areas of the southwest part of the State are largely of Sioux quartzite which in places comes to the surface over areas of several square miles. The rocks have scarcely enough soil over them to support the scanty vegetation. There are a few small areas of granite knobs along the Minnesota Valley from Bigstone Lake down to New Ulm. In the driftless area and part of the drift-covered area in southeastern Minnesota rock ledges of limestone and sandstone outcrop along the steep slopes of the valleys, often forming walls of considerable height. Rock is rarely exposed along the stream beds and valley bottoms. The uplands and the higher parts of the slopes of the valleys even in the driftless area usually have several feet of residuary clay and also a coating of loess or wind-deposited silt loam covering the rock formations and rendering the land tillable.

THE EARTHY MANTLE

GENERAL STATEMENT

The variety of earthy, sandy, and gravelly unconsolidated deposits which cover the rocky floor of Minnesota were formed or deposited by

different agencies and at different times. They may be grouped as follows:

First. Residuary material.
Second. Wind deposits.
Third. Glacial deposits.
Fourth. Stream deposits.
Fifth. Lake deposits.

RESIDUARY MATERIAL

The residuary material, as its name implies, has been left as a residue during the breaking down or decay of the surface rocks through weathering and solution. On limestones it is usually a dark, reddish brown, gummy clay, but on sandstones and crystalline rocks it is usually granular and loose-textured. There is but a small part of Minnesota, chiefly in the southeastern counties, where residuary material is within reach of the plow. It occurs there on the upper part of the slopes of the valleys and on the narrow upland strips between valleys, but is usually covered by loess.

WIND DEPOSITS

Loess.—The wind-deposited material known as loess is largely a fine silt loam, which forms the surface in an area in the southeast part of the State embracing much of Goodhue, Olmsted, Wabasha, Winona, Fillmore, and Houston counties and parts of Mower, Dodge, Rice, and Dakota counties. It covers a small tract in the southwest part of the State in Rock, southern Pipestone, and western Nobles counties. In the southeastern counties it rests in part on glacial drift deposits and in part on the residuary clay and rock formations of the driftless area. In the southwestern part it covers glacial deposits. In the southeast district its border is very irregular, there being long strips of loess-covered land projecting westward or northwestward into the region free from loess, and also long strips free from loess extending eastward into the loess-covered tracts. The condition there is such as might result from the presence or absence of vegetation giving different degrees of protective power from the wind; areas with dense vegetation being able to hold dust that settled from the atmosphere while bare ones allowed it to be gathered up and carried on.

Wind-blown sand.—Wind-blown sand is also an important deposit. It embraces a district east of the Mississippi from Minneapolis up to Brainerd. It is narrow above St. Cloud, but below that city extends eastward to the St. Croix River. The sand does not, however, cover the entire surface in this area. Where present it rests upon glacial deposits. It has low ridges seldom 20 feet and usually 10 feet or less in height.

STREAM DEPOSITS

The stream deposits, being restricted to the valleys, are of limited area, though in such valleys as the Minnesota and Mississippi they are locally several miles in width and form important agricultural belts. On the Minnesota and the part of the Mississippi below the confluence with the Minnesota the deposits made by the rivers are sand or silt. On the Mississippi above the mouth of the Minnesota the deposits range from sand to coarse cobble and bowlders in correspondence with the swiftness of the stream. On nearly all the tributaries of the Mississippi and Minnesota the streams are able to carry coarse as well as fine material. Along the Red River a considerable amount of fine clay and clay loam has been deposited in seasons of flood on the plains outside the immediate river channel. Because of the flatness of the surface many of the small tributaries of Red River have been unable to maintain courses clear through to the river, and so have dropped their deposits where the gradient became too low for the stream to carry them farther. The deposits made by glacial streams or those which had their sources at the edge of the ice and were receiving much of their water from the melting ice, now appear usually as terraces along the valleys above the limits of floods. From the fact that the glacial rivers were of greater volume these deposits are generally composed of sandy and gravelly material somewhat coarser than that carried by the present rivers.

LAKE DEPOSITS

The lake deposits consist of fine sediments washed into the deep parts of the lakes and sandy and pebbly deposits washed up and formed into beaches along the shores. In parts of the lakes where the glacial deposits which they covered were pebbly and the water was shallow enough for wave action, there was a concentration of stony material by the washing-out of the finer material. By this process considerable areas of the bed of Lake Agassiz were covered by very pebbly beds several inches in depth. They are classed on the map of northwestern Minnesota as "lake-washed till." In the narrow strip along the shore of Lake Superior that was covered by the waters of a glacial lake known as Lake Duluth, gravelly and cobbly beaches were formed at several successive levels, while fine material was washed down into the deeper parts of the basin covered by the present lake.

In the Red River Basin and to a slight extent at the west end of e Superior Basin there are fine sediments of considerable depth which close relation to the melting ice and yet are not in all places clearly ble from the lake sediments of later date. While including masses or bowlder clay and nests of bowlders, they are largely of fine ich was laid down at the ice margin in the lake where the ice

A. RIVER SCENE AT ROSEAU, MINNESOTA

B. WHEAT FIELD ON CLAY PLAIN ON BED OF LAKE AGASSIZ

C. HOMESTEAD ON CLAY PLAIN ON BED OF LAKE AGASSIZ

sheet terminated. The supply of material in such cases was from the ice instead of from the washing-in of material from the land outside. The great brickyards at Wrenshall in Carlton County obtain their material from silt deposits of this sort.

THE GLACIAL FEATURES

It has been found through a study of the deposits in Minnesota and neighboring states that the glacial deposits which form so extensive a mantle in Minnesota are the result of more than one invasion of the ice from the Canadian highlands. At each invasion the ice left a deposit of drift gathered partly from Canada and partly from the deposits over which it passed in Minnesota. The advances were so widely separated in time that the drift deposits of one invasion had large valleys cut in them by the action of streams before the next invasion occurred. The later advances failed to cover some parts of the earlier deposits, so they are still exposed to view, and the degree of erosion of the surface of the older can be compared with that on the surface of the younger deposits. It is found that the older drift deposits have been so greatly eroded and are so ramified by drainage lines that no lakes or undrained basins remain on them, while the younger drift deposits have numerous lakes and undrained basins and also large, poorly drained areas which the streams have not yet reached. It is because they are not covered by the latest drift that Rock and Pipestone counties in southwestern Minnesota, and Goodhue, Dodge, Wabasha, Olmsted, Winona, Fillmore, and Mower counties in southeastern Minnesota have no lakes and basins such as characterize neighboring counties that were covered by that drift.

The invasions of the ice into Minnesota not only took somewhat different paths but have come from more than one direction. In the earlier invasions the greater part of the State was covered by ice coming from Manitoba as shown by limestones derived from rock formations of that country which are imbedded in the lower part of the drift over all of the State except its northeast part, and also in the drift of western Wisconsin. The movements in the closing stage of the glacial epoch were more largely from the northeast, there being an extension of ice southwestward from the Superior Basin nearly to Mille Lacs Lake, and an extensive southward movement from the highlands northwest of Lake Superior to points a little beyond St. Paul. But even in this closing stage the ice from Manitoba covered much more than half of the State and on the melting-away of the ice that came from the northern highlands extended over some of the ground that ice had vacated. This is known from the presence of a thin deposit of clayey and limy drift containing rock

material brought from Manitoba over parts of the drift that was deposited by ice coming from the highlands northwest of Lake Superior. The drift from these highlands together with that from the Lake Superior Basin forms the stony red drift of eastern Minnesota, while that from Manitoba forms the clayey and limy gray drift which covers almost all of the remainder of the State.

That the ice mass moved in different directions at different times in certain parts of the State is further shown by striations or ice markings on the surface of the rock ledges. In the district east and south of the Lake of the Woods a set of glacial grooves or ice markings bears west of south, while a newer set crosses them in an eastward or southeastward direction. The older set was formed by ice moving into Minnesota from the highlands that lie between Lake Superior and Lake Winnipeg, while the younger set was formed by ice moving into the State from Manitoba. In North Minneapolis there are rock ledges on which the glacial grooves have three courses; first, a southeastward course at the time when the old gray drift which came from the northwest was brought in; second, a southward course at a time when the red drift which came from the north was deposited; third, an eastward course at the time when the ice from the northwest advanced over land that had been vacated by the ice which deposited the red drift.

GLACIAL LAKE FEATURES

Minnesota contains parts of the beds of two large glacial lakes: Lake Duluth, which occupied the western part of the Superior Basin, and Lake Agassiz which occupied the Red River Basin. Lake Duluth covered a narrow strip along the shore of Lake Superior and extended a few miles beyond the west end of Lake Superior into eastern Carlton County, Minnesota. Its highest stages were about 500 feet above the present surface of Lake Superior. Lake Agassiz extended as far south as Lake Traverse, where it discharged past Brown Valley to the Minnesota. Its border is only from 20 to 30 miles east from the North Dakota-Minnesota line from Lake Traverse northward to Polk County. About 20 miles east-southeast of Crookston it makes an abrupt eastward turn and continues eastward past the south side of Red Lake and on across Koochiching County into St. Louis County as far as the valley of Little Fork River. It then turns northward and enters Canada from northeastern St. Louis County. There were several islands in it in northern St. Louis County.

The western or prairie portion of this lake area was studied by Warren Upham[1] some thirty years ago, and his monograph on the glacial

[1] Monograph XXV, U. S. Geological Survey.

Lake Agassiz contains a large body of important data on this region. In this monograph an island, called Beltrami Island, is represented to cover a large area north of Red Lake. This, however, is now known to have been covered by Lake Agassiz, its highest points being bars of gravel and sand in the lake.

There were also small glacial lakes in other parts of Minnesota where waters were temporarily ponded in front of the ice. These will be mentioned in the description of the counties. None of them, however, fall within the limits of the northwest quarter of the State.

The most prominent features of the two great glacial lakes, Lake Agassiz and Lake Duluth, are the beaches or ridges of sand and gravel washed up along their shores. The shores of Lake Agassiz stand high and dry above the flat parts of the lake bed between or below them and form excellent lines for highways. For this reason much of the pioneer settlement and travel was along these ridges. They generally stand from 5 to 10 feet above the bordering plains and occasionally from 15 to 20 feet. On the inner or lakeward side they are generally more prominent than on the outer or landward side. This is due in part to the original slope toward the center of the lake, but there is also a tendency for a lake to eat back into the bordering land and throw its coarser material up on the edge of the plain outside; at the same time the fine material is carried in suspension from the shore into the deeper water.

The levels of these glacial lakes were lowered from time to time, partly by the cutting-down of the outlets and partly by an uplift of this region which caused the water to fall away where the land rose. There was also a change of outlet in Lake Agassiz from the southern end to the northern and in Lake Duluth from the southward outlet into the St. Croix River to an eastward outlet into the Lake Huron Basin. As a result shore lines were formed at various levels on the slopes of the old lake beds. As a result of the gradual lowering of the water level the greater part of the beds of these glacial lakes has at some time been subjected to wave action. This has produced a widespread pebbly coating which is a concentrate from the washing of the surface of the bowlder clay and the carrying-away of its finer material. Where the bowlder clay was sandy, the sand as well as stones remain, but where it was clayey there is often a clear bed of pebbles a few inches in depth covering the clayey till subsoil. The deep part of Lake Agassiz along the borders of Red River received nearly all the fine sediment which was washed out from the till at higher levels. This forms the bulk of the rich black clay and clay loam of the Red River Basin. At its eastern border 15 to 25 miles from Red River there is a transition to sand. This is succeeded within 2 to 5 miles east by stony sandy deposits which seem to be a glacial material worked over by the lake.

CHAPTER IV

GENERAL SOIL CONDITIONS

Soil is composed of materials derived from the subsoil and mixed with organic matter. Subsoil is the weathered and disintegrated top of the subjacent geological formation. For its qualities and composition the soil of a given region therefore depends quite closely upon the nature of the geological formations there exposed. In Minnesota the land mantle of glacial and lake deposits affords a well-mixed and rich supply of materials suited for soil-making. This is particularly true where it consists of till or bowlder clay in which all classes of material are loosely but thoroughly mixed. This contrasts with soils in which there is too much uniformity and which, when of water-washed sand or gravel, are often deficient in fine material. On the other hand, the loess and the lake silts, though of somewhat uniform texture, make rich soils because of the variety of finely divided minerals which they contain.

The soil and its productiveness depend largely upon the drainage conditions. A soil of clay or clay loam over gravel or loose sand suffers in time of deficient rainfall, while a soil resting upon heavy clay may be drowned out unless surface drainage is perfectly adjusted. For this reason the geologic formation underlying a soil is of great importance. Soil underlaid by limestone, by loess, or by a till consisting of a light clay, or a heavy loam will stand great variation in rainfall and still be highly productive. In some parts of the State the surface drainage is naturally well developed, while in other parts it needs to be greatly supplemented by tile draining or surface ditching.

In the Driftless Area the drainage is everywhere complete, for nearly every acre slopes toward some drainage line. In the old drift also there are few undrained areas and tiling or surface ditching is seldom necessary. In the young drift there are many basins, and undrained depressions and drainage lines are not well distributed over the surface. Except, therefore, where the material is loose enough for the rainfall to be absorbed completely the young drift areas need considerable ditching and tiling. In the bed of Lake Agassiz, although basins and depressions are rare, there are wide areas in which the surface is very flat and extensive and systematic ditching is required to keep the land from being flooded.

VEGETATION

The condition of the soil depends to some degree upon the character of the vegetation which has covered it. In prairie districts there is a more uniform exposure to weathering agencies than in forested districts

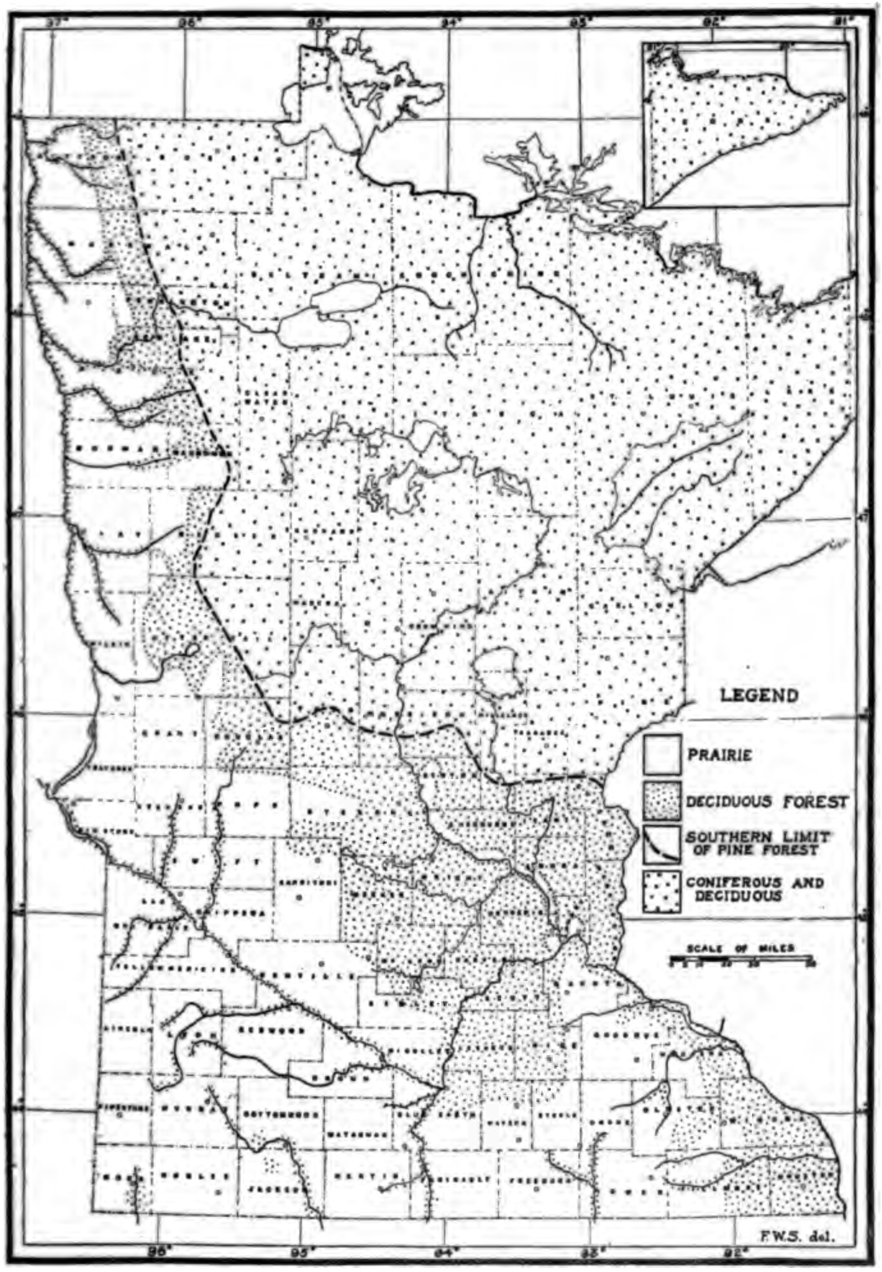

FIGURE 14. MAP OF MINNESOTA SHOWING DISTRIBUTION OF FOREST AND PRAIRIE. (AFTER MAP BY WARREN UPHAM AND BY FREDERIC K. BUTTERS)

CHAPTER V

AGRICULTURAL CONDITIONS AND LAND CLASSIFICATION IN THE NORTHWEST QUARTER OF MINNESOTA

GENERAL STATEMENT

The area embraced in this report covers northwestern Minnesota as far eastward as the 94th meridian and southward to the median line of the State which is near latitude 46° 25′. It embraces about 24,000 square miles outside of Lake of the Woods. The greater part is tributary to Hudson Bay, only 5,600 square miles being tributary to the Mississippi River. Nearly all of this Hudson Bay drainage lies in the bed of the glacial Lake Agassiz. The altitude has a range of about 1,000 feet, or from 750 to 1,750 feet, the highest points being around the head of the Mississippi River. The western part is prairie and the eastern forested land, the line between forest and prairie being from 20 to 40 miles east of Red River. The rainfall ranges from 21 to 28 inches, being lowest on the western border and increasing toward the southeastern.

Settlement began earlier on the prairie portion. Indeed, much of the forested portion still remains unoccupied. Likewise large swamp areas, chiefly in the eastern part of the bed of Lake Agassiz, await artificial drainage before they can be occupied. Four of the great railway systems, the Northern Pacific, Great Northern, Soo Line, and Canadian Northern, have lines traversing northwestern Minnesota and render the greater part of it readily accessible.

In general the supply and quality of well waters throughout the region is good. This region also embraces very extensive flowing well areas in parts of the Red River lowland and in other low areas farther east.

Valuable data on the extent of swamp areas, the direction in which swamps may be most easily drained, and other matters pertaining to drainage conditions, may be obtained from the reports of the State Drainage Commission, from topographic sheets of parts of Ottertail and Becker counties by the United States Geological Survey, and from a report and map of a drainage survey of lands in the region south of Lake of the Woods, published as House Document 27, Sixty-first Congress, First Session. These reports and maps have been of much service in preparing the estimates presented below.

DESCRIPTIONS OF COUNTIES

In the descriptions of counties the first county taken is in the northwest corner of Minnesota, and following this, counties to the east, thence south to the southeast corner of the area embraced in this report, and

A. TILL PLAIN IN MAHNOMEN COUNTY

B. WHEAT FIELD ON TILL PLAIN IN MAHNOMEN COUNTY

thence westward to the southwest corner. General observations concerning settlement and utilization of the land and a few data from the census of 1910, as well as the results of the land classification on a geologic basis, are presented.

KITTSON COUNTY

Kittson County is the northwest corner county of Minnesota and lies entirely within the limits of the glacial Lake Agassiz. As a consequence the classes of land are restricted to lake deposits and lake-washed glacial deposits, though the swamps are covered to considerable extent by peat. The following percentages of each class of land have been computed from field maps. Their distribution in the county may be seen by reference to the general map (Plate I) accompanying this report.

Percentages of Classes of Land in Kittson County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	463	41.7
Sandy deposits of old lake shores	175	15.7
Stony or pebbly sandy loam, lake-washed drift	270	24.3
Stony or pebbly clay loam, lake-washed drift	130	11.7
Swamp land	73	6.6
Totals	1,111	100.0

The black clay and clay loam of the Red River Valley, being a highly productive soil with no forests to remove, has naturally been the first to be taken up for farms. The part of the stony clay loam which borders the black clay loam on the east has also been largely settled and brought into cultivation. Its texture being looser than that of the black clay loam, it is more easily cultivated. The only drawback to cultivation is the presence of surface bowlders which in parts of the area are numerous. They are especially abundant north of Orleans and in the northeast part of the county between Hemmington and Caribou, and in the eastern part north of Pelan. They do not greatly encumber the land in the southeast part of the county or in the district southeast of Orleans.

The areas of stony sandy loam have a variable soil ranging from sandy to gravelly and embracing many patches of clayey drift. The large ditches which traverse the area show abrupt changes from bowlder clay to sand or gravel. In places bowlder clay underlies the sandy gravel at a depth of from only 3 to 5 feet. Such areas and those with a bowlder clay soil are as productive as either of the clay loams. But on the whole the spotted character renders this class of soil somewhat inferior to the areas of clay loam. The land is very thickly strewn with bowlders in

the district between Bronson and Pelan, and is still largely in a wild state. The areas in the northeast part of the county and northeast of Bronson have only a moderate number of bowlders. They embrace much wet land which is as yet only partially drained by artificial ditches.

The sandy land varies greatly as to agricultural conditions. The old shore lines are rather barren because of the relief which they have above the bordering plains and consequent depth of the water table. The sandy plains, for a few miles from the western edge, are generally underlaid by clay at very slight depth and thus have a water table sufficiently near the surface to supply moisture for the crops. In fact some of the sandy land on the immediate border of the black clay loam, as already noted in the general discussion of the region, is preferred as farm land because of its loose texture and easy cultivation. In the northern part of the county the sandy land is so interspersed with marshes that systematic ditching will be necessary to render it suitable for farming. There is an area of sandy land extending from Bronson southward past Halma to the county line with large numbers of surface bowlders, a rather rare feature on so sandy a soil. The presence of the bowlders indicates that the sand may be largely of glacial deposition. The productiveness of the deposit is also greater than in the ordinary lake sand. It is extensively cultivated for potatoes and other root and vegetable crops.

The swamp lands in the eastern part of the county generally have peat and black muck to a depth of from 3 to 6 feet or more, beneath which there is usually a clayey glacial deposit. The swamps in the northern part are more generally underlaid by sand.

Farm and Crop Data for Kittson County from the Census of 1910

Percentage of land area in farms	[illegible]
Percentage of farm land improved	77.2
Average acres per farm	307.5
Average improved acres per farm	[illegible]
Value of all farm property	[illegible]
Percentage of gain since 1900	110.5
Average value of a farm	[illegible]
Cereals produced in 1909	[illegible]
Other grains and seeds	[illegible]
Hay and forage	[illegible]
Vegetables	[illegible]
Fruits and nuts	[illegible]
All other crops	[illegible]
Total crop production in 1909	[illegible]

It should be noted that the prices of farm lands have made a marked advance since 1910, so that the average value for the bare land in 1914 is likely to be nearly $40.00 per acre, and for land with improvements fully $50.00 per acre. The black clay loam of the western part of the county will probably now average nearly $75.00 per acre, if the land carries with it good buildings and improvements.

The most complete settlement is on the black clay loam and the neighboring tracts of sandy land and stony clay loam in the western part of the county, and in the southeast part of the county along the Soo Railroad. But farms are rapidly being developed over the remainder of the county and the large swamps are being drained preparatory to settlement.

ROSEAU COUNTY

Roseau County lies next to the Manitoba line and extends from Kittson County to Lake of the Woods. It is entirely within the limits of the glacial Lake Agassiz and consequently has soils formed from lake deposits or from lake-washed glacial deposits. There is, in its northwestern part, a considerable area of lake clay and clay loam with black soil similar to, and yet isolated from, the area of black clay loam of the Red River Valley. The greater part of the county has soils formed on lake-washed glacial material. Old shore lines and associated sands are, however, conspicuous in the southeastern part of the county, and such a shore line is followed by the Great Northern Railroad from Greenbush nearly to Roseau. There are very extensive swamps in the northern and the southeastern parts of the county on which considerable ditching has been started preparatory to settlement. A great body of first-class land extends from the southwest part of the county northeastward past Roseau to the south fork of Roseau River.

The following estimated percentages of each class of land were computed from field maps. The general map accompanying this report (see Plate I) sets forth their distribution.

Percentages of Classes of Land in Roseau County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	170	10.2
Sandy deposits of old lake shores	210	12.6
Stony or pebbly sandy loam, lake-washed drift	270	16.1
Stony or pebbly clay loam, lake-washed drift	470	28.1
Swamp, largely peat covered	550	33.0
Totals	1,670	100.0

Much of the area of black clay loam in the northern part of the county is under cultivation and it not only supports the three settlements around Pine Creek, Ross, and Duxby, but adds materially to the prosperity of Roseau, the county seat. The areas of stony and pebbly clay land are also very largely under cultivation both in the district southwest from Roseau and that south of Warroad and Swift, but are more slowly developing in the district southeast of Roseau between Falun and Wannaska. Bowlders seldom impede cultivation of the soil.

In the vicinity of America and Clear River there are good farms with sandy soil covering a clay subsoil. In places the sand is so thin that bowlders of the glacial material are only partly covered. In the southwestern part of the county, south from Greenbush, on each side of the Great Northern Railway, the land is very spotted, some farms being largely of pebbly clay loam and others chiefly sandy or gravelly loam. There are also areas of clear sand and gravel extending to the depth of the ditches, 3 to 5 feet or more.

The southeastern borders of the county embrace areas of productive land among the swamps, but much ditching and road-building is necessary there in order to make conditions suitable for successful farming. The areas of lake sand over water-laid moraine (marked on map "*LS over MW*") have a base of glacial material of variable constitution thinly veneered with sandy lake material. In places the bowlders of the glacial formation are visible, though usually they are concealed by the sand.

The swamps of this county form an almost complete barrier to communication with Manitoba, so that customs officials are needed only at Pine Creek and Warroad. A large amount of systematic ditching will be necessary to prepare this swamp for settlement. The amount of peat over much of this area is so great that it presents a forbidding outlook. Yet swamps similar to this, when the water is removed, and intelligent farming methods are employed, often are made to yield profitable returns.

Farm and Crop Data for Roseau County from the Census of 1910

Percentage of land area in farms	29.5
Percentage of farm land improved	49.9
Average acres per farm	196.7
Average improved acres per farm	98.2
Value of all farm property	$6,135,882.00
Percentage of gain since 1900	176.3
Average value of a farm	$3,830.00
Cereals produced in 1909	$430,443.00

Other grains and seeds	**$111,428.00**
Hay and forage	**$163,021.00**
Vegetables	**$64,523.00**
Fruits and nuts	**$270.00**
All other crops	**$49,271.00**
Total crop value	**$818,956.00**

Farm land prices have made a material advance since 1910, much of the good land now being held at from $40.00 to $50.00 per acre.

MARSHALL COUNTY

Marshall County lies immediately south of Kittson and Roseau counties. It extends about 70 miles east from Red River and has a width from north to south of 25.5 miles. The area, as given in the census of 1910, is 1,788 square miles. It is wholly within the limits of the glacial Lake Agassiz and its classes of land are therefore restricted to lake deposits and lake-washed glacial deposits. Much of the stony clay loam land was poorly drained and was classed as swamp land before artificial drainage was established. But only a small part of it has a peaty cover and on that the peat is but a few inches in depth. This land, when properly ditched, can scarcely be distinguished from the areas that were originally classed as dry land. The swamp land with peat cover lies mainly along the northern edge of the county east from the Soo Railroad. There are smaller areas east and south of Mud Lake, and others among the sand ridges east of Viking. The peaty swamp land, however, is estimated to occupy only about 10 per cent of the area of this county.

The following percentages of each class of land have been computed from field maps, and their distribution is shown on the general map (Plate I).

Percentages of Classes of Land in Marshall County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	450	25.2
Sandy deposits, of old lake shores	315	17.6
Stony or pebbly sandy loam, lake-washed drift	175	9.8
Stony or pebbly clay loam, lake-washed drift	665	37.2
Swamp land	183	10.2
Totals	1,788	100.0

The large body of pebbly clay loam in this county, when given proper

Percentage of farm land improved.............	53.1
Average acres per farm........................	207
Average improved acres per farm..............	109.9
Value of all farm property....................	$6,326,149.00
Cereals produced in 1909......................	$548,253.00
Other grains and seeds........................	$100,726.00
Hay and forage................................	$208,626.00
Vegetables	$41,791.00
Fruits and nuts...............................	$817.00
All other crops...............................	$22,923.00
Total crop value..............................	$923,136.00

As in Marshall County the extensive ditching and heavy assessment for draining the wet areas have tended to keep down land prices. Yet the land is increased in value far beyond the expenditure in draining it.

This county is being covered by a detailed soil survey under the Bureau of Soils of the United States Department of Agriculture. The work is in charge of W. G. Smith. In this detailed study, there is of course a more refined analysis and classification of soils than has been attempted by the present writer in the survey of the glacial and lake deposits of this region. This will be brought out in a report by the Bureau of Soils. In the present report and accompanying map (Plate I) Mr. Smith has endeavored to group soils to correspond with the classes shown in the other counties. The percentages of the different classes of soil are based entirely upon the work of the Bureau of Soils and estimated by Mr. Smith.

Statement by W. G. Smith

The western third of the county has been open to settlement something over thirty years, while the remaining eastern portion was opened to settlement only ten years ago.

There is a somewhat uniform but rather sparse settlement all over the county, scarcely half of its area being in farms and less than one third under cultivation. Settlement and enlarging of cultivated acreage seem to be extending rapidly. The land would easily support a much larger population, for it is nearly all of good quality.

The sandy deposits of the old lake shores ("sand ridges") were settled first, as they were not subject to standing water that remained for a long time on the lower lying lands following wet seasons. Since the installation of large drainage ditches throughout the county most of the land is sufficiently protected against standing water to permit of use for farm purposes at all times. Some additional ditching would bring practi-

A. HOMESTEAD ON CLAY MORAINE IN OTTERTAIL COUNTY

B. OATS (AND CORN IN BACKGROUND) ON CLAY MORAINE IN OTTERTAIL COUNTY

cally the whole area of the county within the range of possible use for farm purposes.

Percentages of Classes of Land in Pennington County

	Sq. miles	Per cent of county
Sandy deposits of old lake shores..................	14	2.3
Story or pebbly sandy loam, lake-washed drift......	128	21.1
Stony or pebbly clay loam, lake-washed drift.......	368	60.6
Swamp (peat land).............................	97	16.0
Total	607	100.0

Nearly three fifths of the area of the county has stony or pebbly loam to clay loam surface soils with clay subsoils. Such lands have high agricultural value and under proper cultural methods they have the capacity of producing the staple crops under a wide range of moisture conditions.

About one fifth of the area of the county is covered by sandy loams and loams underlaid by sandy and gravelly subsoils of various depths. While in places the lands are somewhat subject to overdrainage and otherwise show less resistance to drouth than soils having clay subsoils, they should prove to be well suited to agricultural purposes under good cultural methods.

Treeless swamps and peat lands occupy a little less than one fifth of the area of the county. Adequate drainage is one of the first essentials to bring this character of land within the range of usefulness for field-crop purposes. The depth of peat varies considerably, from a few inches to 5 feet or more. The greater depths are found in the east and southeast portions of the county, where the larger areas of peat or swamp lands occur. Some of the townships there have nearly half of their areas covered with swamp or peat. While these areas are not extensively farmed, the staple crops seen growing on peat in some places give the impression that ultimately these peat lands will be subdued to a stage where they may be depended upon to produce profitable crops under a wide range of seasonal variations.

RED LAKE COUNTY

Red Lake County lies south of Pennington and is bordered on the west, south, and east by Polk County. It is traversed by Red Lake River from which its name was derived, as it does not touch upon Red Lake. Since Pennington County was cut off from it there remains an area of only 432 square miles. It is entirely within the limits of the glacial Lake Agassiz, and thus is restricted in soil classes to lake deposits and

lake-washed glacial material. There is a strip of light sandy land on its west border in connection with some of the lower shore lines of Lake Agassiz. The borders of Red Lake Valley, of Clearwater Valley and of its main tributaries, Lost, Hill, and Poplar rivers, have generally a sandy or sandy loam soil, but the greater part of the county has a pebbly clay loam soil, much of which is sufficiently well drained to be suitable for cultivation. There are few places where bowlders are so numerous as seriously to impede cultivation. Some of the sandy land along Clearwater and Red Lake rivers, in the vicinity of Red Lake Falls, is underlaid at slight depth by a lake clay and the sand itself is exceedingly fine-textured. Land of this class is as productive as any in the county. The swamp land is chiefly in the eastern end of the county, and has usually a thin growth of peat over glacial material of variable constitution, with abrupt changes from sand or gravel to pebbly clay.

The following percentages of each class of land have been computed from field maps, and their distribution may be seen on the accompanying general map.

Percentages of Classes of Land in Red Lake County

	Sq. miles	Per cent of county
Sandy and silty lake and stream deposits	110	25.4
Pebbly sandy loam, lake-washed drift	45	10.4
Pebbly clay loam, lake-washed drift	250	58.0
Swamp	27	6.2
Total	432	100.0

There is a somewhat uniform but rather sparse settlement all over this county, scarcely half of its area being in farms, and less than one-third under cultivation. The land would easily support double or treble its present population for it is nearly all of good quality.

Farm and Crop Data for Red Lake County from the Census of 1910

Percentage of land areas in farms	45.4
Percentage of farm land improved	61.5
Average acres per farm	238.0
Average improved acres per farm	189.8
Value of all farm property	$3,711,300.00
Cereals produced in 1909	$363,671.00
Other grains and seeds	$79,828.00
Hay and forage	$94,537.00
Vegetables	$24,028.00
Fruits and nuts	$119.00
All other crops	$12,180.00

POLK COUNTY

Polk County, of which Crookston is the county seat, lies south of Marshall and Red Lake counties, and extends from Red River eastward nearly 70 miles. Its area, as given by the census of 1910, is 1,980 square miles. Its greatest width is at the west in Red River Valley, and nearly half its area has the lacustrine black clay and clay loam. An area of about 500 square miles in the southeastern part lies outside the limits of the glacial Lake Agassiz.

A survey and map of the southwestern part of the county, around Crookston, has been made by the Bureau of Soils of the United States Department of Agriculture.[1] It is chiefly in the area of black clay and clay loam bordering Red River, but its eastern part extends up over some of the lower beaches and associated sandy strips of Lake Agassiz. The northeast part of the map includes a few square miles of stony sandy loam (Benoit fine sandy loam and Benoit loam), a glacial deposit modified more or less by lake action. In the eastern part there are very bowldery areas of lake-washed pebbly clay, classed in part as Benoit loam and in part as Sioux gravelly loam. They are very different from the lake beaches which are composed of sandy gravel and are classed as Sioux gravelly sandy loam. It has been found necessary, therefore, in the present map to depart somewhat from the soil map, in this eastern part of the Crookston area, and make a clear distinction between the lake beaches and the bowldery plain. A large part of the Fargo fine sandy loam of the Crookston area soil map is a deposit such as in other counties of the present report has been classed and represented on the map as lake sand. It has a light soil easily affected by drouth and requiring intelligent cultivation.

The classes of land represented in Polk County include two types of land-laid moraine, the sandy and the clayey, and plains of till or pebbly clay loam, which like the moraines stand above the limits of the glacial Lake Agassiz. The moraines are of a pronounced knob and basin type with numerous small lakes, ponds, and swampy depressions among the knolls and ridges. The till plains are also diversified by small lakes and ponds occupying shallow basins. A few of these are capable of drainage at moderate expense, but the majority have beds below the neighboring drainage lines. Some of the lakes have been partly and others almost completely filled by peaty growths. The extensive swamps are chiefly in the northeastern part of the county on the plain covered by Lake Agassiz, those outside the limits of the old lake being usually too small to admit of representation on the small scale here adopted.

[1] Mangum, A. W., and Schroeder, F. C., Soil survey of the Crookston area, Minnesota: Field operations of the Bureau of Soils 1906.

There is a large peaty swamp in the southwest part of the county across which Sand Hill River discharges by the aid of artificial ditches.

The percentages of the several classes of land here given are based upon field maps and the soil map of the Crookston area. Their distribution is shown on the general map.

Percentages of Classes of Land in Polk County

	Sq. miles	Per cent of county
Sandy moraine	86	4.3
Clayey moraine	73	3.7
Clayey till plain	265	13.4
Sandy soil in till plain	10	0.5
Lake-washed sandy till, pebbly sandy loam	60	3.0
Lake-washed clayey till, pebbly clayey loam	230	11.6
Sandy deposits of old lake shores	305	15.4
Lacustrine black clay and clay loam	835	42.2
Swamps and small lakes and ponds	116	5.9
Totals	1,980	100.0

The wild land in Polk County is found chiefly in the sandy areas and swamps and in the roughest or most hilly parts of the moraines, the first-class land being nearly all in farms. The land outside the limits of Lake Agassiz has about as productive a soil as the clay loams of the old lake area and more productive than the sand and light sandy loams of the lake area. This statement is made since there is a widespread impression that the fertility of northwestern Minnesota land is due to its having once been a lake bed, and it might be inferred that there is a markedly lower degree of fertility outside the lake area. The character of the soil is of course less uniform than in the part of the old lake bed immediately bordering Red River. It is necessary also in a district where ponds and lakes and small peaty basins occur to allow for a considerable percentage of waste land. But the tillable land of southeastern Polk County is a close rival in fertility to that of the Red River Valley. In this part of the county wheat was, for a time, the sole important crop, but now diversified farming is coming into vogue.

Farm and Crop Data for Polk County from the Census of 1910

Percentage of land area in farms	70.2
Percentage of farm land improved	72.4
Average acres per farm	252.2

Average improved acres per farm..............	182.7
Value of all farm property......................	$34,946,027.00
Percentage of increase since 1900..............	78.5
Average value of a farm......................	$9,914.00
Cereals produced in 1909......................	$4,216,361.00
Other grains and seeds........................	$331,471.00
Hay and forage...............................	$670,551.00
Vegetables	$212,600.00
Fruits and nuts..............................	$5,355.00
All other crops..............................	$134,195.00
Total crop value............................	$5,570,593.00

There has been some advance in farm prices since 1910, so that the average value of an improved farm with good buildings may be not less than $50.00 per acre, while farms of this sort in the Red River Valley approach $75.00 per acre.

CLEARWATER COUNTY

Clearwater County was organized in 1903 from the southwest part of Beltrami County and has an area of 1,019 square miles. It is bordered on the west by Pennington, Polk, and Mahnomen counties and on the north and east by Beltrami County. Its northern part extends into the Red Lake Indian Reservation and its southwestern part into the White Earth Reservation. About one fourth of the county, at its northern end, is within the limits of the glacial Lake Agassiz. Its drainage is principally to Clearwater River, from which the county receives its name, but it also includes the headwaters of the Mississippi River and the State Reservation around Lake Itasca.

The portion of this county within the limits of Lake Agassiz is very largely undrained swamp land. Much of it is in the Red Lake Indian Reservation. Notes concerning the character of this swamp land have been furnished by Mr. A. P. Meade of the United States Geological Survey, who in 1913 made a survey for a topographic map of these wet lands. For a few miles along the extreme edge of the area covered by Lake Agassiz there is a sandy to gravelly loam with till of very variable constitution at slight depth and noted on the map *LST*. Farther out there is a general coating of peat over a clayey glacial deposit with local patches of sand and gravel, as in the part of Pennington County adjoining it on the west.

The part of the county outside the limits of Lake Agassiz is largely tillable land, its character being similar to that of the adjoining part of Polk County. It includes both the sandy and clayey moraines and ex-

tensive till plains of a prevailingly clayey constitution. There are numerous small lakes and swamps among the morainic knolls and ridges, and also scattered lakes and shallow swampy basins in the till plains. It is difficult to estimate the aggregate amount, but probably not less than 20 per cent of the area of the moraines and till plains of this county are water and waste land, which is not taken into account in the table below. There are extensive swamps in the southern part of the county extending out in all directions from Rice Lake, and others farther north in the vicinity of Bagley and Shevlin which are included in the swamp land in the table.

The percentages of the several classes of land here given are based upon field maps and to some extent on the notes by Mr. Meade.. Their distribution is shown on the general map.

Percentages of Classes of Land in Clearwater County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil....	173	17.0
Clayey moraine, with pebbly clay loam soil........	180	17.6
Clayey till, with pebbly clay loam soil.............	208	20.4
Till plain with sandy patches.....................	30	3.0
Outwash gravel, and glacial drainage deposits.....	71	7.0
Lake-washed till, largely loose-textured...........	97	9.5
Sandy gravel of lake shores......................	20	2.0
Swamps and small lakes and ponds...............	240	23.5
Totals	1,019	100.0

The lightest soils of the county are found in the outwash gravels and lines of glacial drainage and in the beaches of sandy gravel on the shore of Lake Agassiz. They are composed very largely of sand and fine gravel with only a slight amount of loam in the soil. The sandy moraines usually have a considerable admixture of loam with the sand and gravel which gives them a somewhat higher degree of fertility than the outwash plains and beaches. Portions of them, however, are greatly interrupted by small swamps and deep basins which render cultivation of the land rather difficult and in consequence only a small part of this land has been brought under cultivation. The wet lands of the northern portion of the county lie largely in the Red Lake Indian Reservation, but outside the reservation are very sparsely settled. They need considerable ditching to render them tillable. The areas of clayey moraine and clayey till which constitute about three eighths of the county have highly productive soils, but as yet only a small portion of the land is

improved. Settlement is more or less retarded from the fact that it is a forest-covered tract.

Farm and Crop Data for Clearwater County from the Census of 1910

Percentage of land area in farms	26.8
Percentage of farm land improved	23.2
Average acres per farm	165.5
Average improved acres per farm	38.4
Value of all farm property	$3,150,087.00
Cereals produced in 1909	$146,906.00
Other grains and seeds	$3,940.00
Hay and forage	$128,655.00
Vegetables	$39,659.00
Fruits and nuts	$461.00
All other crops	$65,326.00
Total crop value	$384,947.00

BELTRAMI COUNTY

Beltrami County extends from the Lake of the Woods southward past Red Lake to the line of Hubbard County. The south boundary is about 100 miles from the southernmost point on Lake of the Woods. There is also a small detached area known as the Northwest Angle lying west of Lake of the Woods whose northernmost point is about 135 miles from the Hubbard County line. In its widest part the county embraces nine ranges of townships or 54 miles. The census of 1910 gives the county an area of 3,822 square miles. This evidently does not include Red Lake and probably does not include the small lakes inside the county. The total area of Red Lake is 440 square miles, of which 408 square miles fall within the townships and ranges embraced in Beltrami County. The small lakes embrace about 100 square miles. The sum of the sections and parts of sections outside of Red Lake is 3,924 square miles. If 102 square miles are allowed for the small lakes, the land area is reduced to what is given by the census report, or 3,822 square miles. In the estimates of percentages given below it has been found necessary to include the small lakes as has been done in other counties, not only for the sake of uniformity, but also because it is not possible in some cases to draw the line between lake and swamp. The lakes and swamps are accordingly grouped together, and the percentages are estimated on the basis of an area of 3,924 square miles.

The greater part of Beltrami County lies within the limits of the glacial Lake Agassiz, whose southern shore passes along the south side

of Red Lake. As already noted, it was once supposed that a part of Beltrami County north of Red Lake stood above the level of Lake Agassiz and was called Beltrami Island. The highest points in that district, however, have bars of sandy gravel on them formed by Lake Agassiz. A considerable part of the bed of Lake Agassiz within the limits of Beltrami County is still a muskeg swamp which can be traversed only with great difficulty except when frozen. Through the heroic efforts of Mr. Meade and his party of surveyors it was traversed sufficiently to obtain data necessary to construct the topographic and drainage map which accompanies House Document 27 of the Sixty-first Congress, First Session. Mr. Meade has also kindly furnished such information as he had gained concerning the character of the soil of the small islands that rise here and there above the level of the muskeg. Information concerning the soil on some of the islands has been obtained from Mr. A. R. McDonnell, of Baudette, who had made timber estimates on them for lumber companies and who was the present writer's guide over parts of the district. The data are thus such as were noted incidentally in the course of other investigations and should be read with this understanding. As far out as settlements have reached, the present writer gave the soil personal examination.

Data concerning soils on the Northwest Angle were obtained from Mr. E. C. Barnard of the United States Coast and Geodetic Survey, who was in charge of the survey along the boundary between Minnesota and Manitoba in 1912 and 1913. Data on islands in Lake of the Woods were kindly supplied by Mr. W. A. Johnston of the Geological Survey of Canada who cruised among them and studied their geology in the summer of 1913. Mr. Johnston also supplied notes concerning the occurrence of lake clay over glacial deposits along the shore of Lake of the Woods and in the bluffs of Rainy River in this county.

The district south of Red Lake stands above the level of Lake Agassiz, and here roads are few and much of the land is still in forest. It was not possible, therefore, to obtain such full knowledge of the soil conditions as in the districts to the west where forests have been cleared and farms opened. Diligent inquiry was made, however, throughout this part of the county, of residents who had some personal knowledge of the character of the land.

Nearly all the rock outcrops of this northwest quarter of Minnesota are in the northern part of Beltrami County. They occur here and there for several miles south of Rainy River and Lake of the Woods, as well as on islands in Lake of the Woods, but their aggregate area is estimated to be only 8 square miles. Usually a rock knob on the mainland occupies only an acre or two, but there are a sufficient number to amount to a square mile or more of bare rock. On the islands in Lake

VIEWS ON GRAVEL OUTWASH PLAIN NEAR WADENA

of the Woods much of the surface is bare rock except Garden Island. This, Mr. Johnston reports, is thickly covered with a calcareous bowlder clay, and it derives its name from its having been cultivated to some extent.

Percentages of Classes of Land in Beltrami County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil....	145	3.7
Clayey moraine, with pebbly clay loam soil........	170	4.3
Outwash gravel, and sandy glacial drainage deposits	216	5.5
Till plains with prevailingly clay loam soil.........	393	10.6
Till plains with mixed soil, sandy to clayey.......	72	1.8
Stony or pebbly clay loam, lake-washed drift.....	292	7.4
Stony or pebbly sandy loam, lake-washed drift.....	266	6.7
Sandy and gravelly deposits of old lake shores....	207	5.0
Lake clay	23	0.6
Rock outcrops..................................	8	0.2
Small lakes....................................	102	2.5
Swamp land.....................................	2,030	51.7
Totals	3,924	100.0

The settlements in the northern part of the county are chiefly within 10 miles of the Canadian Northern Railroad, and even here only a small percentage of the land is cleared and cultivated. There are a very few residences along Rapid River and Rainy River, and a few scattered over the high tract of gravel and sand from 12 to 15 miles south and southwest of Williams.

There are prosperous settlements in the district northwest of Red Lake, with post-offices at Malcolm, Thorhult, Jelle, Carmel, and Orheim. Grain and produce is marketed at Thief River Falls though this point is distant fully 50 miles from the eastern part of this farming district. Large ditches have been made and others are in course of construction which will give the region fair drainage. The soil is largely a pebbly clay loam, strewn thickly in places with bowlders, but generally supplied with only a sufficient number to provide foundations for buildings. The roads, which usually follow the lines of the ditches and utilize the embankments, are in good condition for hauling heavy loads to the distant market. This district had only a scattered and stunted forest cover so that it has been easier to bring it into cultivation than the heavily forested areas south of Red Lake.

In the part of the county south of Red Lake farming is chiefly carried on in the areas of pebbly clay loam and gravelly areas near Bemidji and south and west from that city. There is very little settlement as yet between Bemidji and Red Lake. There are small settlements along the eastern border near Kelliher, Funkley, Black Duck, and scattered settlers southward past Louis to the border of Cass Lake. The prevailing soil there is a pebbly clay loam, but it is interrupted by patches of sandy or gravelly soil. Much remains to be done in ditching the land and in road-building as well as in clearing of forests to bring this district into a condition of full cultivation, but the fertility of the soil is such as to encourage such development.

Farm and Crop Data for Beltrami County from the Census of 1910

Percentage of land area in farms	9.1
Percentage of farm land improved	14.9
Average acres per farm	141.9
Average improved acres per farm	21.1
Value of all farm property	$3,389,856.00
Cereals produced in 1909	$56,646.00
Other grains and seeds	$5,031.00
Hay and forage	$127,054.00
Vegetables	$126,585.00
Fruits and nuts	$1,221.00
All other crops	$286,922.00
Total crop value	$601.459.00

WESTERN KOOCHICHING COUNTY

Only the western three ranges of townships in Koochiching County, embracing an area of 1,027 square miles, will be considered in this report. It so happens that it includes the part of the county in which swamps are most extensive, and thus is not fairly representative of the county as a whole. About 80 per cent of this part of the county lies within the limits of the glacial Lake Agassiz, but about 200 square miles in the southern end stand above the highest shore line.

There are a few rocky knobs near Manitou Rapids and southwestward from there, and also near Clementson, but they aggregate scarcely a square mile in area.

The cultivable land in the portion within the limits of Lake Agassiz is mainly along the borders of the streams. In most places muskeg swamps set in within a mile back from these drainage lines. This is true even on the borders of Rainy River, in places where its valley is

from 30 to 40 feet deep. There are belts of sandy land, in part moraine and in part beach or shore deposit, which cross the interstream areas and break the continuity of the muskeg swamps. On one of the sandy strips near Wayland a few settlers have located. There are also a few in the vicinity of Norden, on the borders of Tamarack River, and on sand ridges to the south. Only small clearings have as yet been made by any of the settlers, and the narrowness of the cultivable strip will greatly restrict farming operations under present conditions of drainage. Several good county roads are projected across these swampy districts, and some are in process of construction.

In the portion of this county above the level of the highest shore of Lake Agassiz a large percentage of the land is tillable with but small expenditure for ditching, and this portion of the county is being developed rapidly. The soil is mainly a pebbly clay loam, but there are morainic strips in which gravelly and sandy knolls occur, and the soil is generally loose-textured, though quite productive.

Percentages of Classes of Land in Western Koochiching County

	Sq. miles	Per cent of area
Sandy moraine, with sandy to gravelly loam soil....	54	5.2
Till plain, with prevailingly clay loam soil.........	146	14.2
Stony or pebbly clay loam, lake-washed drift......	114	11.1
Sandy and gravelly deposits of old lake shores.....	57	5.6
Rock knobs....................................	1	0.1
Swamp land....................................	655	63.8
Totals	1,027	100.0

NORTHWESTERN ITASCA COUNTY

An area of about 470 square miles in the western three ranges of townships in Itasca County will be discussed in this report. The south part is included in the Minnesota National Forest, and is uninhabited. The remainder is a very sparsely populated district, there being few farms except in the vicinity of the Minnesota and International Railroad, which crosses the northwest corner of the county. Much of this district is practically inaccessible unless one forces his way through brush and swamp, there being very few roads or trails across it. Considerable information has, however, been obtained in reference to it from residents who have had occasion to go into this district.

Aside from a morainic strip which runs southeastward from Orth past Island Lake to Popple, this district seems to be occupied entirely

by till plains and swamps. It is thought, however, that the wet land may be easily drained when the brush is removed and a moderate amount of ditching is done. The soil appears to be subject to abrupt changes from clay to sand or gravel, and the designation *TM* on the general map stands for mixed soil in a till plain. Of the 470 square miles fully 80 per cent is in the till plain. The sandy moraine occupies about 7 per cent. There thus remains about 10 to 12 per cent in lakes and swamps.

PARTS OF CASS AND CROW WING COUNTIES

The greater part of Cass and a few townships in the northwest part of Crow Wing County fall in the southeast part of the area embraced in this report. It is made to include the whole of the three townships southeast of the Mississippi River in Crow Wing County since they extend but a slight distance outside the limits of the map. But north of the Mississippi the estimates do not extend east of Range 27, as only a small part of Range 26 is within the limits of the map. In making the percentage estimates of the different classes of land Leech Lake and Winnibigoshish Lake are not included. Leech Lake has an area of 173 square miles at low-water stage and Winnibigoshish an area of 77 square miles. The smaller lakes of this district are estimated to have an aggregate area of about 177 square miles and the swamps 133 square miles. There is thus 560 square miles of lakes and wet land or about 25 per cent of the entire district. But counting out Leech and Winnibigoshish lakes and thus reducing the district 250 square miles, the lakes and swamps comprise 15.6 per cent, of which 8.9 per cent is lake and 6.7 per cent swamp. The area of the district as thus reduced is 1,990 square miles.

This district is separable into several distinct belts. At the north, along the south side of the Mississippi River and Winnibigoshish Lake, there is a plain of sandy gravel with forest of Norway pine which extends south about to the line of the Great Northern Railroad. South of this on the borders of Leech Lake is a great till plain with a pebbly clay loam soil to the northwest of the lake, and with a mixed or variable soil to the east and southeast. Extensive tracts of wet land are present on the plain east of Leech Lake. On the immediate south border of this lake there is a rolling country with stony or pebbly clay loam soil. This changes on the south into a more sandy and gravelly tract of moraine which covers several townships of this district and extends westward in a broad belt across Hubbard County to the headwaters of the Mississippi in Clearwater County. This moraine loses expression, however, toward the east side of the district under discussion and consists of scattered groups of knolls bordered by nearly plain tracts of mixed clay and

sand and gravel. From Whitefish Lake southward to Gull Lake and eastward to the Mississippi is a gravelly glacial outwash plain with numerous basins containing lakes. The strip of gravelly glacial outwash extends from Whitefish Lake northwestward past Backus along the south side of the great moraine just mentioned. The morainic tract has an offshoot to the south from near Hackensack which separates this gravelly outwash plain from a larger one in Hubbard and Wadena counties. In the southwest part of the district are several townships with gently undulating clayey moraines and bordering till plains. The till plains are in part clayey and in part have mixed soil with abrupt and frequent changes from pebbly clay to gravel or sand. In the extreme southeast part of this district on the east side of the Mississippi there is a rugged sandy moraine with small outwash gravel plains included among groups of morainic knolls.

Percentages of Classes of Land in Parts of Cass and Crow Wing Counties

	Sq. miles	Per cent of district
Sandy moraine, with sandy to gravelly loam soil...	379	19.0
Clayey moraine, with pebbly clay loam soil........	191	9.6
Outwash gravel plains.........................	540	27.1
Clayey till plain, with pebbly clay loam soil........	205	10.2
Till plain with mixed soil, clayey to sandy or gravelly	365	18.3
Swamps	133	6.7
Small lakes........	177	8.9
Totals	1,990	99.8

This district has farming settlements in the western part along the line of the Minnesota and International Railroad and the Great Northern Railroad which extend over the till plains and clayey moraines of the southwest part. There is also a settlement at Longville, southeast of Leech Lake. The remainder of the district is very sparsely inhabited. The soil of much of this district is rich enough to justify large expenditures in road-building and in draining the land and in clearing it of brush. The heavy soil of the till plains and clayey moraines of Cass County is well adapted for stock-raising and dairying as well as general farming. The iron mines in the southeast corner of this district have brought in a large population which gives a good home market for garden produce and dairy products of that locality.

HUBBARD COUNTY

Hubbard County is a rectangular tract seven townships long and four townships wide lying west of Cass and south of Beltrami County. It contains 1,008 square miles, of which about 93 square miles are estimated to be covered by small lakes. The census of 1910 gives the land area as 958 square miles, some of the lakes apparently being included.

The southern end of the county is occupied by a large plain of sandy gravel in which there are a number of small lakes and marshes of considerable extent. North of this is a great moraine of sandy and gravelly constitution, in which a number of lakes are included, and from which the sandy outwash of the plain to the south was derived. On its north border the moraine becomes more clayey and graduates into a till plain which occupies much of the northern third of the county. There are small areas of sandy land along the north border, one being in the northeast corner near Farris, and another a few miles southwest of Bemidji, both of which extend into the great sandy plain of the southern part of Beltrami County. The till plain has a pebbly clay loam soil and constitutes the best farming land in the county, there being several prosperous farming settlements on it. A portion of the sandy plain in the southern part of the county had no forest on it at the time the country was settled, so that farms were easily cleared and brought into cultivation. The district around Park Rapids and Hubbard was therefore settled long before the neighboring forested areas.

Percentages of Classes of Land in Hubbard County

	Sq. miles	Per cent of county
Sandy moraine, with light sandy to gravelly loam soil	267	26.5
Clayey moraine, with pebbly clay loam soil	151	15.0
Outwash gravel plains	153	15.1
Till plain, with pebbly clay loam soil	224	22.2
Small lakes	93	9.3
Swamp land	120	11.9
Totals	1,008	100.0

Farm and Crop Data for Hubbard County from the Census of 1910

Percentage of land area in farms	24.8
Percentage of farm land improved	36.6
Average acres per farm	180.3

Average improved acres per farm	66.1
Value of all farm property	$3,175,028.00
Percentage of gain since 1900	212.1
Cereals produced in 1909	$171,961.00
Other grains and seeds	$9,417.00
Hay and forage	$116,760.00
Vegetables	$89,302.00
Fruits and nuts	$1,029.00
All other crops	$74,052.00

A considerable part of the gain in value of farm property in Hubbard County is due to development of new farms. The average value of land per acre in 1900, according to the National Census, was $7.10, or slightly more than half of that of 1910. The present value of land is somewhat higher than in 1910, and may average, with improvements included, about $30.00 per acre.

WADENA COUNTY

Wadena County embraces only fifteen townships or an area of 540 square miles. Its southern edge extends 3 or 4 miles beyond the southern limits of the map accompanying this report, but the discussion embraces the whole county. The greater part of this county is a sandy outwash plain, a southward continuation of that in Hubbard County. Along the west border, however, there is a till plain with pebbly clay loam soil embracing an estimated area of 117 square miles, or, including swamps, a little more than one fifth of the county. The southern end of the county, in the vicinity of the Northern Pacific Railroad, has been settled for many years. The western range of townships, along the line of the Great Northern Railroad, has more recently been converted into farms. But in the northeast part of the county there are still very few settlers. That part of the county has considerable wet land. The entire county has been estimated by George A. Ralph to contain 80,000 acres of swamp (*Drainage Engineer's Report*, 1906).

In the part of this county south of Leaf River there was a re-advance of ice over the gravelly outwash which greatly increased the fertility by introducing clayey calcareous drift a few feet thick and mixing it with the gravel. The farms are kept in a good state of fertility by the growing of clover which thrives on this soil.

Farm and Crop Data for Wadena County from the Census of 1910

Percentage of land area in farms	46.1
Percentage of farm land improved	43.9

Average acres per farm	158.0
Average improved acres per farm	69.4
Value of all farm property	$4,697,499.00
Percentage of gain since 1900	130.00
Cereals produced in 1909	$263,978.00
Other grains and seeds	$13,170.00
Hay and forage	$136,990.00
Fruits and nuts	$486.00
All other crops	$45,269.00
Total crop production in 1909	$512,294.00

NORTHERN OTTERTAIL COUNTY

The map accompanying this report includes twenty-six full townships and parts of nine other townships in the northern part of Ottertail County. The discussion and estimates here given will cover the entire thirty-five townships or 1,260 square miles.

In the northeastern part of the county there is an area of about 200 square miles of till plain with a pebbly clay loam soil, parts of which are thickly strewn with bowlders. It includes a few small lakes and swamps, and, until cleared of brush, parts of it are poorly drained. The surface, however, is undulating and but a moderate amount of ditching will be required to render much of the wet area suitable for cultivation.

In the northern and central parts of the county there is a very rugged moraine of sandy constitution with local developments of clayey drift. This includes a multitude of small lakes and undrained basins which in several townships comprise nearly half the surface. Estimates of the percentages of dry and wet land made from the topographic sheets of the United States Geological Survey, are presented below. In a large part of this area of morainic drift it would be difficult to find a square mile of land free from swamp or lake, and in some townships there is scarcely a 40-acre lot free from wet land. The slopes of the morainic knolls are also steep, as may be seen by an inspection of the topographic sheets. It is an interesting fact that this morainic area with its extremely rough surface stands almost in sight of the featureless plains of the Red River Valley, a few miles to the west. Here it would be difficult to carry a straight furrow for more than a fraction of a mile, while on the neighboring plains there is nothing to turn the plow aside. This rugged district, known as the Park Region of Minnesota, seems best adapted for grazing and dairying. The soil is of sufficient strength to give good pasturage, while there is no lack of water supply for the stock.

The western limits of this rugged moraine are at the east side of

A. DRAINING A MUSKEG SWAMP IN ROSEAU COUNTY

B. DRAINED SWAMP IN PENNINGTON COUNTY WITH FOREST ON LAKE-WASHED TILL IN BACKGROUND

Pelican River Valley. To the west of that valley is a moraine of clayey constitution and more gently undulating surface. This is in places thickly set with small lakes but the amount of lake and marsh is scarcely half as great as in the more rugged moraine to the east. Almost the entire area of this clayey moraine is under cultivation and the marshy ground is utilized to a considerable extent for pasturage. This tract stands at the border between forest and prairie, only a part of its surface being occupied by forests and groves.

There is an extensive outwash plain around Ottertail Lake and Rush Lake, and lines of glacial drainage come down to it from the north. One of these is along the line of Ottertail River and the other along Toad River. In this outwash plain and the lines of glacial drainage just mentioned, lakes and basins are very numerous, as in the rugged moraine to the west, but there is a much smaller amount of swamp land than in the moraine. The dry land also has a level surface and thus contrasts strikingly with the rugged surface of the moraine. This plain varies in fertility in proportion to the amount of loam in the soil and in proportion to the nearness of the water table to its surface. The soil is, however, on the whole lighter than that of the neighboring moraines.

There are two sharp gravel ridges, termed eskers, in the northeastern part of Ottertail County, one being east of Pine Lake, and the other on the upland south of Perham. These are more winding and sharper than the shore lines of the glacial Lake Agassiz, but like the shore lines are composed of sandy gravel. Ridges of this class often occur on till plains where gravel for roads is an important asset. The ridge east of Pine Lake may thus serve a useful purpose.

Percentages of Classes of Land in Northern Ottertail County

	Sq. miles	Per cent of district
Sandy moraine, with sandy to gravelly loam soil....	258	20.4
Clayey moraine, with pebbly clay loam soil........	160	12.7
Outwash gravel and sandy glacial drainage deposits.	229	18.2
Till plain, with prevailingly clay loam soil.........	217	17.2
Lakes and swamps............................	396	31.5
Totals	1,260	100.0

The estimates of swamp land and lakes in the Perham, Vergas, Battle Lake, Underwood, and Fergus Falls topographic sheets,[1] so far as they fall within this district, have been computed section by section, and their

[1] These topographic sheets are obtainable at 10 cents each, or $6.00 per hundred sheets, from the Director U. S. Geological Survey, Washington, D. C.

aggregate for each township follows. The border between lake and swamp is in many cases so indefinite on the topographic sheets that separate estimates have not been made.

Percentage of Lakes and Swamps in Certain Townships of Northern Ottertail County

	Sq. miles	Per cent lakes and swamps
Western third of T. 137, R. 38 W.	3.6	30
Western third of T. 136, R. 38 W.	5.6	47
Western third of T. 135, R. 38 W.	6.2	51.6
Western third of T. 134, R. 38 W.	1.7	14
T. 137 N., R. 39 W.	11.4	32
T. 136 N., R. 39 W.	5.9	17
T. 135 N., R. 39 W.	16.6	46
T. 134 N., R. 39 W.	18.9	52.5
T. 137 N., R. 40 W.	14.6	40
T. 136 N., R. 40 W.	16.2	45
T. 135 N., R. 40 W.	20.4	56.6
T. 134 N., R. 40 W.	20	55.5
T. 137 N., R. 41 W.	9.5	27
T. 136 N., R. 41 W.	14.6	40.5
T. 135 N., R. 41 W.	23.1	64
T. 134 N., R. 41 W.	12	33.3
T. 137 N., R. 42 W. (two thirds of township)	10.6	44
T. 136 N., R. 42 W. (five sixths of township)	20.9	70
T. 135 N., R. 42 W. (33 square miles)	12.8	39
T. 134 N., R. 42 W.	12.5	34.7
T. 135 N., R. 43 W. (south half)	3.6	20
T. 134 N., R. 43 W.	11.9	33
T. 135 N., R. 44 W. (15 square miles)	2.8	18.66
T. 134 N., R. 44 W. (30 square miles)	6.7	22.3

BECKER COUNTY

Becker County lies north of Ottertail County and embraces 40 townships, or 1,440 sections. The number of square miles, as estimated by Upham in his report on Becker County for the Geological Survey of Minnesota, is 1,445.41. Upham also estimated the area of lakes in this county to aggregate 137.5 square miles, thus leaving a land area of 1,308 square miles. The swamp land as estimated by the present writer amounts to about 250 square miles.

Becker County includes the continuation of the same series of moraines, till plains, and outwash gravel plains, which have been described in northern Ottertail County. There is a bowlder-strewn till plain in the southeast part. North and west of this are extensive plains of outwash gravel, and beyond these the very rugged sandy moraine, while farther west are gently undulating clayey moraines and till plains. In the midst of the great sandy moraine there is an outwash plain setting in immediately north of the city of Detroit and extending southwestward into northwestern Ottertail County, with a general width of 4 or 5 miles. Its surface is more undulating than the ordinary outwash plains, and lakes of considerable size lie in it or on its border. It contrasts strikingly with the neighboring moraines in its freedom from bowlders, and it also lacks the loam which is generally present on the moraines. A similar gravelly outwash tract is present in the midst of the great sandy moraine in the northern part of the county a few miles east of the White Earth Agency.

The White Earth Indian Reservation occupies twelve townships in the northern part of the county. In this reservation considerable land is cultivated on the till plains and clayey moraine along and west of the Soo Railroad, and a small tract is cultivated on the outwash gravel plain north of Ponsford. With these exceptions the portion of the reservation in Becker County is practically in its wild state.

The western part of Becker County is along the border line between the forest and prairie, and is practically all under cultivation, and the major portion of the land is settled as far east as Richwood, Detroit, and Frazee. There are also old settlements on the outwash gravel plains around Ponsford and Osage, a considerable part of the plain being prairie or covered by a very scrubby timber. The ease of clearing such land compared to that of the heavily forested but richer land to the south accounts for its earlier settlement. Even now there is very sparse settlement of the southeast part of the county, though it is well suited for agriculture. On the rough morainic land east from Richwood farming is scarcely yet begun. There is a belt several miles wide running southward across the county along either side of Ottertail River which seems well suited for grazing land, but much of it is rather broken for farming.

Percentages of Classes of Land in Becker County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil...	402	28.2
Clayey moraine, with pebbly clay loam soil........	160	11.1
Outwash gravel and glacial drainage deposits.....	239	16.6

	Sq. miles	Per cent of county
Till plain, with pebbly clay loam soil	253	17.6
Swamp land	247	17.0
Lakes	137	9.5
Totals	1,440	100.0

Farm and Crop Data for Becker County from the Census of 1910

Percentage of land area in farms	41.1
Percentage of farm land improved	50.4
Average acres per farm	171.2
Average improved acres per farm	86.3
Value of all farm property	$11,795,410.00
Percentage of increase since 1900	124.2
Cereals produced in 1909	$976,176.00
Other grains and seeds	$64,545.00
Hay and forage	$300,673.00
Vegetables	$100,164.00
Fruits and nuts	$6,045.00
All other crops	$108,225.00
Total crop value	$1,556,328.00

MAHNOMEN COUNTY

Mahnomen County was organized from a part of Norman County in 1906 and embraces the greater part of the White Earth Indian Reservation, there being sixteen townships or 576 square miles in the county. The western half is almost entirely a clayey till plain and this plain extends a few miles into the eastern half, in the central portion of the county. It is diversified by a few gravelly knolls, and also by a few small lakes. The eastern half is largely morainic, the northeastern portion being a clayey moraine and the southeastern portion more sandy and gravelly. A line of glacial drainage with sandy soil runs along the east border of the northern half of the county, and then leads southwestward past Twin Lakes into northern Becker County.

Percentage of Classes of Land in Mahnomen County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil	70	12.2
Clayey moraine, with pebbly clay loam soil	146	25.5
Outwash gravel and sandy glacial drainage deposits	25	4.5

	Sq. miles	Per cent of county
Clayey till plain, with pebbly clay loam soil........	309	54.0
Lakes and swamp land..........................	22	3.8
Totals	572	100.0

The western half of the county is largely prairie and contains nearly all the land under cultivation. Fully three fourths of the prairie, however, is in a wild state, though having a very rich soil.

Farm and Crop Data for Mahnomen County from the Census of 1910

Percentage of land area in farms.................	11.5
Percentage of farm land improved................	57.4
Average acres per farm..........................	169.3
Average improved acres per farm.................	97.3
Total value of farm property...................	$1,234,111.00
Cereals produced in 1909.......................	$94,707.00
Other grains and seeds........................	$13,248.00
Hay and forage................................	$23,793.00
Vegetables	$8,884.00
Fruits and nuts...............................	$9.00
All other crops...............................	$4,994.00
Total crop production in 1909.................	$145,635.00

NORMAN COUNTY

Norman County, which borders on Red River, has, since Mahnomen County was cut off, an area of 860 square miles. All of this except 125 square miles on the eastern border was covered by the waters of the glacial Lake Agassiz. Nearly half the county has the rich black clay and clay loam of the Red River Valley. On the eastern border, above the limits of the lake, there is a till plain, nearly all prairie, with rich black pebbly clay loam soil. Between the clay belt of the Red River Valley and this till plain is a sandy belt from 8 to 15 miles wide on which occur a number of successive shore lines of Lake Agassiz. These shore lines are narrow ridges of sand or sandy gravel occupying scarcely more than one tenth of the sandy belt. Just below the upper beach there are narrow strips of lake-washed till with sandy to clay loam soil. A few sand dunes occur in the northeast part of the county, and there is some sand on the till beyond the limits of the lake east of Flaming and northward to Fertile in Polk County. In the southeast part of the county outside the limits of Lake Agassiz there are scattered clusters of gravelly knolls rising

from 50 to 75 feet above the surrounding till plain. These may mark a temporary ice border and thus be of morainic character.

Percentages of Classes of Land in Norman County

	Sq. miles	Per cent of county
Gravelly glacial knolls	3	0.3
Till plain with sandy patches	14	1.6
Till plain with black pebbly clay loam soil	102	11.9
Lake shores and associated sand	265	30.9
Stony or pebbly sandy loam, lake-washed drift	50	5.8
Black clay and clay loam, lacustrine	405	47.1
Swamp land	21	2.4
Totals	860	100.0

Aside from a part of the sandy land, Norman County has an exceptionally productive soil, and as indicated by the table below, it is very largely under cultivation. Wheat, oats, and barley are raised in large amounts. Farm prices have made some advance since 1910, the average value of a farm with good buildings being now fully $50.00 per acre.

Farm and Crop Data for Norman County from the Census of 1910

Percentage of land area in farms	76
Percentage of farm land improved	75.2
Average acres per farm	253.2
Average improved acres per farm	190.4
Value of all farm property	$16,371,171.00
Average value of a farm	$9,904.00
Cereals produced in 1909	$2,013,945.00
Other grains and seeds	$146,889.00
Hay and forage	$274,104.00
Vegetables	$59,918.00
Fruits and nuts	$3,043.00
All other crops	$37,643.00
Total crop value in 1909	$2,535,542.00

CLAY COUNTY

Clay County, of which Moorhead is the county seat, has an area o 1,043 square miles and extends from Red River eastward a few mile beyond the limits of the glacial Lake Agassiz. The western third of th

has the black clay and clay loam of the Red River Valley; but a water-laid moraine with surface bowlders and looser soil trav- ; southern part centrally from north to south. East of the black trict is a strip of sandy land from 6 to 10 miles wide, in which successive beaches of Lake Agassiz are present. There is also '-laid moraine among the beaches and partly covered by lake Barnesville stands on it and it is well developed for several miles f that village. In the vicinity of Barnesville it is thickly strewn wlders, but farther north they are usually covered by lake sand. northeastern part of the county, outside the limits of Lake Agas- 'e is a till plain with rich prairie soil of slightly pebbly clay loam. ear Hitterdal southwestward to Muskoda there is a moraine with us basins and small lakes among its swells and ridges. From la it runs southward along the border of Lake Agassiz. It is y composed of clayey till but includes some gravelly knolls and ndy land. Outside of this moraine is a strip of gently undulating ı level patches of gravel and sand which follows down Buffalo o Hawley, but is very narrow farther south. In the southeast the county is a prominent moraine which extends into Becker ertail counties. It has a rich prairie soil with pebbly clay loam sub- :s surface is rolling, but its slopes are gentle enough for easy on. It includes a number of small lakes, and a small percentage ıpy land.

Percentages of Classes of Land in Clay County

	Sq. miles	Per cent of county
noraine, with sandy to gravelly loam soil...	10	1.0
noraine, with pebbly clay loam soil........	157	15.0
aid moraine with variable soil.............	16	1.5
n with pebbly clay loam soil..............	120	11.5
r pebbly sandy loam, lake-washed drift.....	28	2.8
leposits and old lake shores of pebbly sand..	305	29.2
ay and clay loam, lacustrine..............	400	38.4
land..................................	7	0.6
ls	1,043	100.0

'm and Crop Data for Clay County from the Census of 1910

entage of land area in farms...............	79.6
entage of farm land improved.............	82.0
:age acres per farm.......................	305.8

Average improved acres per farm	250.8
Value of all farm property	$23,924,607.00
Percentage of increase since 1900	100.4
Cereals produced in 1909	$2,622,637.00
Other grains and seeds	$112,902.00
Hay and forage	$447,917.00
Vegetables	$607,158.00
Fruits and nuts	$3,840.00
All other crops	$21,634.00
Total crop value in 1909	$3,816,088.00

NORTHERN WILKIN COUNTY

An area of 381 square miles in northern Wilkin County, comprising townships 134 to 136 N., ranges 45 to 48 west, is here discussed. It falls within the limits of the glacial Lake Agassiz, except a narrow strip from 1¼ to 4 miles wide on the eastern border which rises above the level of that lake. The black clay and clay loam of the Red River Valley extends only 1 to 2 miles east from the river at the southern edge of this district, and about 7 miles at the northern. There is a tract of lake-washed till extending from near the river eastward to the upper beach of Lake Agassiz in T. 134 N., Rs. 45 to 47 W., and the south part of T. 135 N., Rs. 45 to 47 W. Farther north in the northern part of T. 135 N., Rs. 45 to 47 W., and in T. 136 N., Rs. 45 to 47 W., there is a sandy coating over the till, so that it is exposed in only a few narrow strips. Several ridges of sandy gravel, marking the shores of Lake Agassiz, traverse the eastern part of this district, and scattered ridges occur farther west, there being a prominent one from 3 to 6 miles north-northeast of Kent, and less conspicuous ones a few miles farther north.

The water-laid moraine on which Barnesville stands runs southward through the eastern part of T. 136 N., R. 46 W. and has a strong beach developed on its western slope. The part of the district standing above the level of Lake Agassiz consists of a narrow till plain immediately east of the high shore line, and a clayey moraine along the eastern side of the county which extends into Ottertail County.

With the exception of a few small brushy areas along the streams this is a prairie region and the clayey portion has a rich black soil. The sandy portions vary considerably in fertility. A few square miles in T. 135 and 136 N., R. 47 W. have a light sand which is subject to drifting by the wind. The old shore lines are composed of a sandy gravel with rather light soil, but sandy tracts among them have an admixture of loam, and also have less depth to the water table, so that they are moderately productive.

Percentages of Classes of Land in Northern Wilkin County

	Sq. miles	Per cent of district
Clayey moraine, with pebbly clay loam soil..........	22	5.8
Till plain, with pebbly clay loam soil...............	28	7.4
Stony or pebbly sandy loam, lake-washed drift......	102	26.7
Pebbly clay loam, lake-washed drift...............	58	15.2
Sandy desposits of Lake Agassiz.................	91	23.9
Black clay and clay loam, lacustrine...............	70	18.4
Swamp land	10	2.6
Totals	381	100.0

The extent of cultivation of the land in Wilkin County is about the same as in northern Clay County, and there is a similar land value and crop production.

The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY

WILLIAM H. EMMONS, DIRECTOR

IN COÖPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 13

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BY

FRANK LEVERETT

AND

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WITH A CHAPTER ON

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INTRODUCTION

By W. H. Emmons

Soil is the loose unconsolidated material which nearly everywhere covers the surface of the earth and in which plant life may be maintained. It is made up of finely divided rock in which decaying vegetable matter and animal matter are mingled. A soil is generally in a state of change. It is being washed little by little to the creeks and rivers which carry it to the sea, where it often forms delta deposits; if no new soil formed, hard rock would finally be exposed instead of the loose plant-producing soil. But rocks at and near the surface are continually changing and new soil is being formed from the underlying rock or from loose clayey or gravelly material that may constitute the subsoil, or from bowldery material that at many places in Minnesota lies between the hard rock and the soil.

Water and air attack rock matter and break it down. Heat and cold, freezing and thawing, shatter the rocks and give plants an opportunity to send roots into the cracks that are formed, and these, prying the rocks apart, reduce them to particles of still smaller size. Even the hard, solid rocks are ultimately broken down; a building of good solid stone may crumble in a few hundred years, particularly in a moist climate.

Some of the rocky matter is dissolved by the water and carried to the sea in solution. It is such dissolved material that makes water "hard" and that gathers in the bottom of a vessel when water is boiled. But not all of the soluble substances are dissolved and carried away; some remain in the soil and the character of the soil depends largely upon these. Some soils are acid because they have not enough lime. Some are deficient in potash or phosphates, which are necessary if soil is to produce certain crops satisfactorily.

Because it forms the soil, the composition of the underlying material is of great importance. In Minnesota most of the soil is the weathered portion of glacial drift or of lake beds and other features connected with the deposition of the drift. Long ago nearly all of what is now the state of Minnesota was covered over with a great ice sheet hundreds of feet thick that slowly moved down from the Canadian highland carrying with it rocky material which it had gathered in the north. When the ice melted it left large quantities of rock and soil that had mingled with the ice and this material is the loose drift that lies between the hard rock and the surface. At many places where it is not yet disintegrated it appears as large groups of bowlders mixed with clay. Although the

ice sheet moved very slowly, perhaps not more than a few rods a year or even less, it was active for a long period and locally it scoured the country clean of soil and loose material which on melting it piled up somewhere else.

This statement of the origin of the loose material or drift is not speculation, but is substantiated by the most convincing facts. The deposits and all of the features of the country formerly covered with ice are like those that may now be observed in Greenland or Antarctica, where the slowly moving ice fields or glaciers still cover bodies of land of continental proportions. Glacial bowlders, bowlder clay, scratches on the rocks, morainal hills and kettles, all ordered with respect to definite features of the former ice sheet, may be seen at thousands of places in Minnesota.

In the northern parts of Cook, Lake, and St. Louis counties the ice sheet removed the soil and subsoil, laying bare the underlying hard rock. Before the ice melted in this region it had carried the loose material away. Since that time there has been some weathering of the rock, but at most places not enough to give a good workable soil. Many of these areas are in the Superior National Forest and are well suited for growing forests although they have little or no value for farming. In the southern parts of these counties near the lake there are areas with loose sandy soil well suited to growing garden truck.

The last great ice sheet that covered the area melted very slowly and the southern part was melted long before the northern part. The ice that still remained in the north formed a great dam which held back the drainage of the Red River basin and formed a large lake which is called the glacial Lake Agassiz. This extended from the Red River Valley and plains of Manitoba as far east as the western part of the area herein described, covering nearly all of Koochiching County and the northwestern part of St. Louis County. When the ice retreated and this lake was drained, there were left the old beach ridges which now supply building sites and road material. Extensive beds of lake sediments were left also, and when these are suitably drained they make good soil. Other lakes smaller than Lake Agassiz, but yet extensive, were formed also. When they were drained, their beds likewise became available for plant growth and where properly drained they generally make good soil, especially where the soil contains sufficient clay.

Swamps are very numerous in the northeast quarter of the state. They are portions of the old lake beds and other poorly drained areas and are of little value for agriculture until drained. Since the ice melted a growth of vegetation has been established on them and great thicknesses of partially decayed vegetation have accumulated in them. This forms

the peat which is found in so many of the swamps. Some of it is very thick and will doubtless become a valuable asset in the future when other fuels shall have become more costly.

The great productivity of Minnesota soils is due, not only to their recent origin by reason of which nearly all of them still contain the soluble mineral foods for plants, but also to a favorable climate. The low temperatures which frequently prevail during certain periods in winter make for healthful conditions for animal life and they also benefit plant life. The rainfall, though not excessively great, is sufficient and, since most of it occurs during the growing period, drouths are rare and crop failures almost unknown except in the more sandy soils, which are, however, adapted to quick-growing crops like potatoes. As shown herein, the length of the crop-growing season, that is, the time between late spring frosts and early autumn frosts, is between 100 and 170 days for all except the extreme northeast corner of the state. The long days, high proportion of sunshine, and the moderate humidity are all favorable to plant growth.

This bulletin is a preliminary paper which treats the soils of only the northeast quarter of Minnesota. It will be followed by a report on the entire state, the field work for which already has been completed. The work has been done in accordance with the agreement for coöperation between the United States Geological Survey and the Minnesota Geological Survey, entered into, March, 1912. By this agreement the services of Mr. Frank Leverett were secured for surveying the surface formations and soils. Mr. Leverett has been engaged since 1886, or thirty years, in studying the surface geology of the Great Lakes region and because of his large experience in the greater area he was particularly well prepared to undertake the studies in Minnesota. He has spent, moreover, considerable time in the state studying its physiography in connection with the preparation of a monograph for the United States Geological Survey. Since the reorganization of the State Survey, the salary of Mr. Leverett has been met by the United States Geological Survey, while the greater part of his expenses have been paid by the State Survey. The State Survey has provided also for this work the services and expenses of Professor F. W. Sardeson, who has assisted in this work for the past five seasons. For a short period, also, the State has supplied the services of Dr. Arthur H. Elftman. We wish to acknowledge the generous assistance of the Division of Soils of the Department of Agriculture of the University of Minnesota and of the United States Bureau of Soils. The valuable contributions to the knowledge of the surface formations of Minnesota by the Minnesota Geological and Natural History Survey, under the direction of Professor N. H. Winchell, particu-

y those of Mr. Warren Upham of that Survey, have aided greatly e preparation of this report. The section on climatic conditions in iota has been generously contributed without any cost to the Sur- Mr. U. G. Purssell, Director of the Minnesota Section of the ed States Weather Bureau. In the preparation of the maps and data showing dates of killing frosts, lengths of growing season, nfall, etc., Professor C. J. Posey has rendered efficient service.

The cost of preparation of this report has been met by the Minne- ota Geological Survey and the United States Geological Survey. This is printed by the Minnesota Geological Survey. Arrangements e been made so that land and onization companies can secure these rts at actual cost of printing, and it is expected that this arrange- ent will secure a wide distribution. The maps are not intended to be sed as a basis for the purchase of land; they do not give an accurate cription of each forty-acre tract or each section, but they show the eral classification of the land, its climate, and its surroundings.

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS IN NORTHEASTERN MINNESOTA

By Frank Leverett and Frederick W. Sardeson

FIELD WORK AND ACKNOWLEDGEMENTS

The field embraced in this report on northeastern Minnesota includes the whole of Cook, Lake, and St. Louis counties, and parts of Koochiching, Itasca, Cass, Crow Wing, Aitkin, and Carlton counties. Its southern limit is the median line of the state, which is near latitude 46° 25′, and its western line is the 94th meridian. It embraces about 17,280 square miles, a little more than 20 per cent of the state.

Following the plan in *Bulletin No. 12,* on Northwestern Minnesota, a brief general description of the surface features and deposits of the entire state is given, and the climate of the entire state also is discussed.

In addition to the field work by the authors, assistance was rendered by Earl R. Preston for two months in studies in Cook, Lake, and St. Louis counties. In the study of these counties assistance was also rendered by Dr. Arthur H. Elftman for a brief period. Dr. Elftman had, some years previously, explored a considerable part of Lake and Cook counties as a member of the Geological Survey under Professor N. H. Winchell, and was thus able to supply valuable data in reference to parts of the county which now are not easily accessible, because of the lack of roads or trails, and which were then studied by working out from camps and by canoe trips through the lakes and connecting streams. In the preparation of this report much aid has been derived from the publications of the Geological and Natural History Survey of Minnesota, prepared under the direction of Professor N. H. Winchell. Much use has been made also of the volume by George A. Ralph, State Drainage Engineer, entitled *Topographical and Drainage Survey of Minnesota for 1906.* Its maps have been especially valuable as a basis for estimating the swamp land areas, and its lines of levels for drawing the contours which appear on Plate I of the present report. Aid has been rendered also by numerous residents of the region in supplying information and in guidance through parts difficult of access, a kind of assistance which is especially valuable in a region so sparsely inhabited and imperfectly opened to travel.

CHAPTER I

PHYSICAL FEATURES OF MINNESOTA

TOPOGRAPHY OF MINNESOTA

GENERAL STATEMENT

The position of Minnesota is near the center of the North American Continent, and the state embraces an area of 84,682 square miles, of which about 93 per cent is land and 7 per cent water. Its extreme length is nearly 400 miles, from latitude 43° 30′, at the Iowa line, to a point about 23 miles north of the 49th parallel, in the projection known as the Northwest Angle, northwest of Lake of the Woods. The greatest width is 367 miles, but the average width is only about 225 miles, or but little more than half of the length.

Minnesota presents more variety in surface features than most of the north central states, yet a great part of its surface is level or only gently undulating. The flattest portion falls largely in the northwest quarter, and was once the bed of the glacial Lake Agassiz, a lake held in on the north, in central Canada, by the great ice sheet. The roughest portion is in the northeastern quarter within the area embraced in this report. This part is composed largely of volcanic formations and iron-bearing rocks which, though glaciated, were not everywhere buried beneath the glacial deposits. In the southeastern part of the state deep erosion valleys along the Mississippi and its tributaries present bold rock bluffs 300 to 600 feet high. The interior and southern parts of the state have features due almost entirely to the work of the great ice sheets, which at successive times, and from different directions, overspread Minnesota. The glacial deposits comprise an intricate system of moraines with undulating to hilly surface, associated with which are level outwash plains of sand and gravel, and gently undulating intermorainic till plains. The moraines were formed along the border of the ice at definite lines where the edge of the ice held its position for a relatively long time. They consist of sharp knolls and inclosed basins and also of more or less parallel ridges which, however, interlock in places. These moraines are distributed in rudely concentric systems which mark successive positions of the border of each ice sheet as it was melting off from this region. The outwash plains lie on the outer border of the moraines, where sandy gravel was spread out by dirt-laden waters escaping from the ice. The till plains lie along the inner or iceward border of the moraines and represent areas over which the ice border melted back somewhat rapidly, forming relatively few knolls and ridges.

ALTITUDE

The altitude of Minnesota ranges from 602 feet, the level of Lake Superior, up to 2,230 feet, on high rock hills in the northeast part of the state, in western Cook County. The small map, Figure 1, shows that a large part of the state falls between 1,000 and 1,500 feet. The average altitude of the state is not far from 1,200 feet. The portions above 1,500 feet lie chiefly in two areas, one at the northeast and one at the southwest corner of the state, though there is a good sized area around the sources of the Mississippi River in the western part, and several smaller areas in that vicinity; one of these in the southern part of Otter Tail County is known as the Leaf Hills. The altitude of the elevated area in the southwestern part falls short a little of reaching 2,000 feet, but that in the northeastern part includes several small areas, chiefly in Cook County, that rise above 2,000 feet. The portions below 1,000 feet fall in two areas widely separated except for a connecting line along the Minnesota valley, one being on the western edge of the state and the other on the eastern. There is also a narrow strip bordering Lake Superior. The 100-foot contours which appear on the glacial and soil map of northeastern Minnesota (Plate I), show the altitude relations in the district embraced in the present report, while Figure 1 sets forth the conditions for the remainder of the state.

RELIEF

The most conspicuous relief is found in the "Sawtooth Range" and other prominent ridges that closely border Lake Superior and which rise abruptly from 500 to 900 feet above the lake. The rock ranges lying back from the shore, though more elevated than those fronting on the lake, seldom rise more than from 200 to 300 feet above the swamps and lakes among them. In fact several of the lakes of Cook County are above 1,900 feet or within 300 feet of the level of the highest points in the state. The most prominent part of the Mesabi Iron Range in St. Louis County rises from 400 to 450 feet above bordering plains. The Coteau des Prairies rises about 700 feet above the plain northeast of its border, but in Minnesota the rise is usually spread over a space of from 12 to 15 miles or more in width, so that the elevation can scarcely be appreciated by one crossing over it. There is a rather rapid rise of from 300 to 500 feet to the sharp range of hills in Otter Tail and Becker counties from the Red River valley. This rise is of especial interest since it seems to have some influence on the rainfall, the precipitation being greater in these hills where air currents are forced upward and cooled than in the bordering lower lands to the north, west, and south.

FIGURE I. ALTITUDE MAP OF MINNESOTA

EXPLANATORY NOTE, FIGURE 1

This map shows the great extent of land in Minnesota standing between 1,000 and 1,500 feet above sea level, as well as the distribution of the higher areas and of areas standing below 1,000 feet.

It shows also the effect of low areas in favoring the movement of the latest invasion of ice from the north, that which deposited the young gray Keewatin drift, as well as the effect of the high areas in checking the movement. The great axial movement of the ice was through the low-lying Red River basin, much of which is below 1,000 feet, and thence down the Minnesota valley to the great bend at Mankato over a plain much of which is below 1,100 feet. The thumb-like offshoot of the ice, in a lobe extending from Wright and Hennepin counties northeastward across Anoka, Isanti, and Chisago counties, into the edge of Wisconsin, was apparently induced by an exceptionally low area, largely below 1,000 feet, over which it passed. In northern Minnesota the ice passed over the relatively low land, 1,200 to 1,300 feet, along and near the Mississippi River in Cass and Itasca counties, into the St. Louis River basin in St. Louis County, and down the Mississippi in Aitkin County; but it was so checked by higher land, 1,500 to 1,750 feet, in Clearwater, Becker, and Hubbard counties, that it could there reach only southeastern Hubbard and neighboring parts of Cass and Wadena counties. The Mesabi Range also held the ice border back nearly to the western edge of St. Louis County while it pushed eastward some distance in St. Louis County, both north and south of the range.

The topography also influenced ice movement in the northeast part of the state. There was a strong movement of ice southwestward through the Superior basin, with its northwest border only a few miles back from the shore on the high land, much of which stands 1,500 feet or more above the sea. This high land was largely covered by a southward ice movement from still higher land in the neighboring part of Canada. The relations of this ice movement to that in the Superior basin, as well as to that which covered western Minnesota is set forth in the discussion of the glacial deposits.

DRAINAGE

The drainage of Minnesota is widely divergent, part of it leading to the Gulf of Mexico, part to the Gulf of St. Lawrence, and part to Hudson Bay. The Gulf of Mexico receives about 57 per cent, the St. Lawrence less than 9 per cent, and Hudson Bay fully 34 per cent of the drainage. There was a time, however, after the glacial ice had melted from Minnesota but was still occupying the northeast part of the Superior basin and neighboring parts of Ontario and Manitoba, when all the drainage was southward to the Gulf of Mexico. The western Superior basin then overflowed into the St. Croix River, while the Red River drainage basin, largely covered by Lake Agassiz, drained southward through Lakes Traverse and Bigstone into the Minnesota valley.

The drainage to the south, or Gulf of Mexico, has generally a gentle descent, and waterfalls are rather rare, though the Mississippi has notable falls at Minneapolis and there are one or more falls or rapids on several of the tributaries. The drainage to Lake Superior is generally rapid and nearly every stream has several cascades. There is, however, a wide area of the upper St. Louis basin in which that stream and its tributaries have relatively gentle descent for many miles. The Hudson Bay drainage has a few rapids and waterfalls in the headwater part of Rainy River and its tributaries, but Red River and its main Minnesota affluent, Red Lake River, have no falls since no outcrops of solid rock occur along them. There is, however, very rapid descent for a few miles along Red Lake River and its tributary Clearwater River in Red Lake County. Red River is subject to great freshets because its lower course often remains frozen after the southern or headwater part has broken up. Thus ice jams are formed which divert the waters from the channel over the bordering plain.

Of the 17,280 square miles of the area embraced in the present report, 5,550 square miles drain to Lake Superior, 8,042 square miles to Rainy River of the Hudson Bay drainage system, and 3,688 square miles to the Mississippi River and tributaries. The streams of these several drainage systems are interwoven in the western part of the area, there being no prominent dividing ridges to separate them. In some cases a swamp may be drained either to the Hudson Bay or to the Gulf of Mexico system, while other swamps may be drained either to the Mississippi system or to Lake Superior. In the northeastern part of the area there is less interweaving of the drainage, though even there easy canoe portages are made between the Hudson Bay drainage and the drainage to Lake Superior.

LAKES

Throughout much of Minnesota, except the northwest, southwest, and southeast corners, small lakes are a common feature. They usually occupy basins among the moraine ridges and knolls and on the outwash plains, but occur to some extent also on the till plains and among rock knobs. The combined area of the lakes within the state is estimated to be about 5,650 square miles, or nearly 7 per cent of the entire area. The largest lake is Red Lake, a very shallow body of water with an area of 440 square miles. Other large lakes are Mille Lacs, also very shallow, Leech, Winnibigoshish, and Minnetonka. Minnetonka and the southern part of Leech Lake extend into a network of deep depressions among morainic ridges, but the other lakes are largely in plains that are slightly below the neighboring districts, partly morainic and partly plain.

SURFACE GEOLOGY

ROCK AREAS

The areas in which rock is so exposed as to render the land untillable are largely in the northeast quarter of the state, or along valleys in the southeast quarter. The northwest quarter is estimated to have less than 10 square miles of bare rock outcrop, and the southwest scarcely 100 square miles. It is doubtful if there is an area of 1,000 square miles in the entire state in which the plow would generally strike into rock ledges. The rock areas thus form a much smaller percentage of the state than the lake areas. The rock areas of the northeast part are chiefly rock bosses standing above the surrounding land, but the beds of the streams that lead directly down to Lake Superior are also usually on rock ledges. Among the rock knobs are some depressions covered only with moss and peaty material, glacial material being scanty, but ordinarily some glacial material is present and nearly all the land has soil enough over the bedrock to support a rich forest growth. Many of the knobs preserve the smooth surface left by the scouring effect of the ice sheet and are nearly destitute of vegetation. But certain others have become disintegrated to a depth of several inches or even to several feet from the surface and are supporting growths of vegetation of considerable density.

The rock areas of the southwest part of the state are largely of Sioux quartzite which in places comes to the surface over areas of several square miles. The rocks have scarcely enough soil over them to support the scanty vegetation. There are a few small areas of granite knobs along the Minnesota Valley from Bigstone Lake down to New Ulm. In the driftless area and part of the drift-covered area in southeastern Minnesota, rock ledges of limestone and sandstone outcrop along the steep

slopes of the valleys, often forming walls of considerable height. Rock is rarely exposed along the stream beds and valley bottoms. The uplands and the higher parts of the slopes of the valleys even in the driftless area usually have several feet of residuary clay and also a coating of loess or wind-deposited silt loam covering the rock formations and rendering the land tillable.

THE EARTHY MANTLE

GENERAL STATEMENT

The variety of earthy, sandy, and gravelly unconsolidated deposits which cover the rocky floor of Minnesota were formed or deposited by different agencies and at different times. They may be grouped as follows:

First. Residuary material.
Second. Wind deposits.
Third. Glacial deposits.
Fourth. Stream deposits.
Fifth. Lake deposits.

RESIDUARY MATERIAL

The residuary material, as its name implies, has been left as a residue during the breaking down or decay of the surface rocks through weathering and solution. On limestones it is usually a dark, reddish brown, gummy clay, but on sandstones and crystalline rocks it is usually granular and loose-textured. There is but a small part of Minnesota, chiefly in the southeastern counties, where residuary material is within reach of the plow. It occurs there on the upper part of the slopes of the valleys and on the narrow upland strips between valleys, but it is usually covered by loess.

WIND DEPOSITS

Loess.—The wind-deposited material known as loess is largely a fine silt loam, which forms the surface in an area in the southeast part of the state embracing much of Goodhue, Olmsted, Wabasha, Winona, Fillmore, and Houston counties and parts of Mower, Dodge, Rice, and Dakota counties. It covers a small tract in the southwest part of the state in Rock, southern Pipestone, and western Nobles counties. In the southeastern counties it rests in part on glacial drift deposits and in part on the residuary clay and rock formations of the driftless area. In the southwestern part it covers glacial deposits. In the southeast district its border is very irregular, there being long strips of loess-covered land projecting westward or northwestward into the region free from loess, and

A. SUPERIOR RED DRIFT OVER PATRICIAN RED DRIFT NEAR CLOQUET. THE MAN SITS ON A BOULDER AT THEIR JUNCTION

B. CLAYEY KEEWATIN DRIFT OVER STONY PATRICIAN DRIFT AT BIWABIK

also long strips free from loess extending eastward into the loess-covered tracts. The condition there is such as might result from the presence or absence of vegetation giving different degrees of protective power from the wind; areas with dense vegetation being able to hold dust that settled from the atmosphere while bare ones allowed it to be gathered up and carried on.

Wind-blown sand.—Wind-blown sand is also an important deposit. It embraces a district east of the Mississippi from Minneapolis up to Brainerd. It is narrow above St. Cloud, but below that city extends eastward to the St. Croix River. The sand does not, however, cover the entire surface in this area. Where present it rests upon glacial deposits. It has low ridges seldom 20 feet and usually 10 feet or less in height. There is more or less wind-drifted sand in the sandy parts of the St. Louis River drainage basin, but it is sparingly developed compared to that in the district between the Mississippi and St. Croix rivers. Wind-blown sand occurs also in Aitkin County in the vicinity of McGregor and also in the northeastern part of the county in island-like tracts that are surrounded by marshes. There are numerous small areas of such sand scattered over the state, some of them being along the shores of the glacial Lake Agassiz.

GLACIAL DEPOSITS

The glacial deposits as shown in Figure 2 extend over the entire state except eastern Winona County and the greater part of Houston County, which are in the driftless area of the upper Mississippi. They underlie the wind-deposited sands and much of the loess area. They also underlie stream deposits and lake sediments. The glacial deposits are separable into till or bowlder clay in which stones, clay, and sand are closely commingled; and into sand or gravel beds which show some assorting and bedding by water action. The percentage of stony material varies greatly and the matrix also shows variations from compact clay to loose sand. These variations are to be expected in a deposit that had been formed from the dirt and stones included in an ice sheet. Every observing farmer has probably noted and perhaps speculated upon the cause for these variations in the drift deposits which form the basis for so large a part of the Minnesota soil. The assorted sand and gravel beds are largely due to waters escaping from the melting ice and many of them may be traced up to a moraine which marked the position of the ice border at the time they were laid down. They show a decrease in coarseness in passing away from the edge of the moraine, the coarse material having been dropped close to the edge of the ice and only the fine carried to a great distance outside.

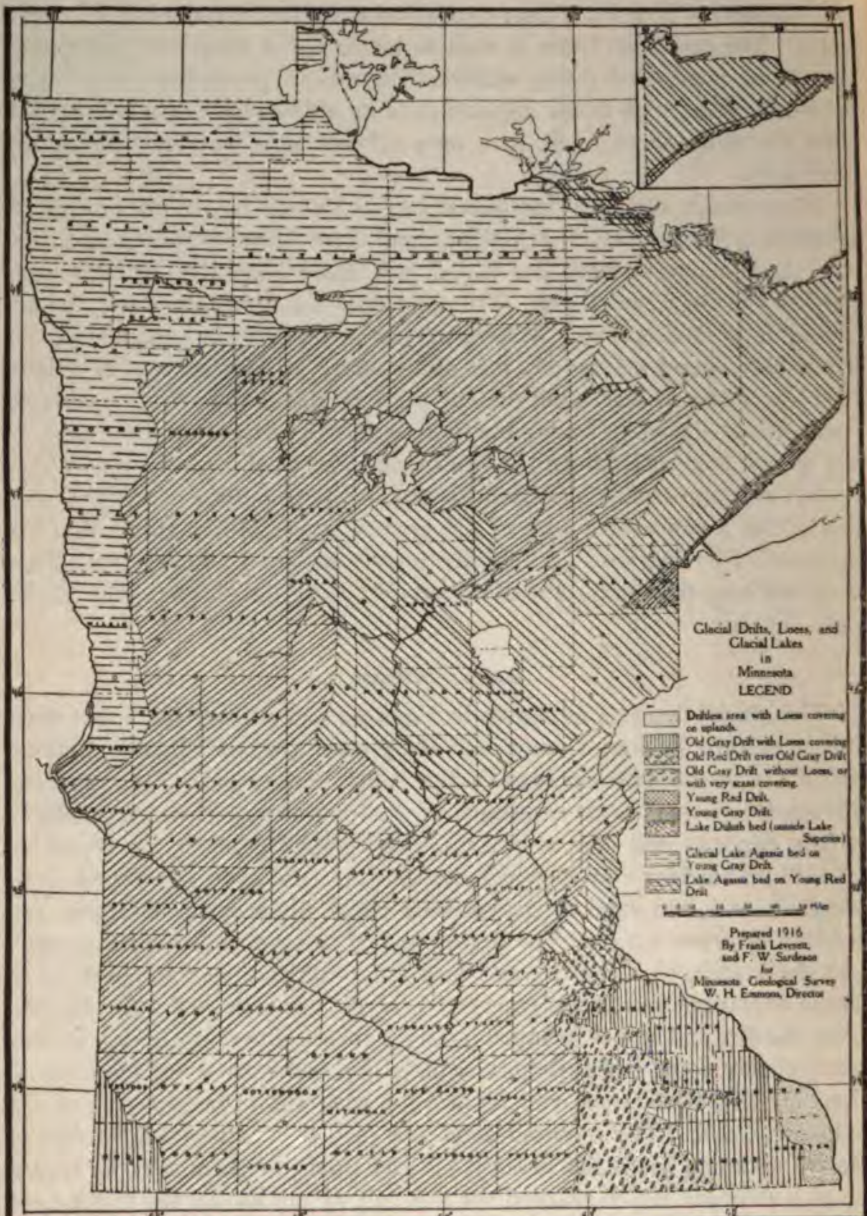


FIGURE 2. MAP OF GLACIAL DRIFTS, LOESS, AND GLACIAL LAKES IN MINNESOTA

The glacial deposits also show some variations that relate to the kind of rock formations over which the ice passed. Thus, the northeastern portion of the state has a rather stony drift from the volcanic and hard crystalline rocks of that region. This stony material was carried as far south as Dakota County and forms the red drift of eastern and northeastern Minnesota. As indicated below, the red drift is the product of more than one ice sheet. The western and southern parts of the state have a large amount of clayey drift material with limestone pebbles imbedded. This material was gathered by this ice as it passed across in its southward course from the shales and limestone of southern Manitoba, that greatly dominate there over the granite and other crystalline rocks. These clayey and limy deposits form what is known as the gray drift of Minnesota, and the ice sheet which formed it, as the Keewatin ice sheet.

STREAM DEPOSITS

The stream deposits, being restricted to the valleys, are of limited area, though in such valleys as the Minnesota and Mississippi they are locally several miles in width and form important agricultural belts. On the Minnesota and the part of the Mississippi below the confluence with the Minnesota the deposits made by the rivers are sand or silt. On the Mississippi above the mouth of the Minnesota the deposits range from sand to coarse cobble and bowlders in correspondence with the swiftness of the stream. On nearly all the tributaries of the Mississippi and Minnesota the streams are able to carry coarse as well as fine material. Along the Red River a considerable amount of fine clay and clay loam has been deposited in seasons of flood on the plains outside the immediate river channel. The deposits made by glacial streams or those which had their sources at the edge of the ice and were receiving much of their water from the melting ice, now appear usually as terraces along the valleys above the limits of floods. From the fact that the glacial rivers were of greater volume these deposits are generally composed of sandy and gravelly material somewhat coarser than that carried by the present rivers.

LAKE DEPOSITS

The lake deposits consist of fine sediments washed into the deep parts of the lakes, and sandy and pebbly deposits washed up and formed into beaches along the shores. In parts of the lakes where the glacial deposits which they covered were pebbly and the water was shallow enough for wave action, there was a concentration of stony material by the washing-out of the finer material. By this process considerable areas of the bed of Lake Agassiz were covered by very pebbly beds several inches in depth. They are classed on the soil maps as "lake-washed till." In the

narrow strip along the shore of Lake Superior that was covered by the waters of a glacial lake known as Lake Duluth, there is very little fine sediment; gravelly and cobbly beaches were formed at several successive levels, while fine material was washed down into the deeper parts of the basin covered by the present lake. Fine material also covers the old lake plain in Carlton County and a strip on the south side of Lake Superior.

THE GLACIAL FEATURES AND THEIR HISTORY

It has been found through a study of the deposits in Minnesota and neighboring states that the glacial deposits which form so extensive a mantle in Minnesota are the result of more than one invasion of the ice from the Canadian highlands. At each invasion the ice left a deposit of drift gathered partly from Canada and partly from the deposits over which it passed in Minnesota. The advances were so widely separated in time that the drift deposits of one invasion had large valleys cut in them by the action of streams before the next invasion occurred. The later advances failed to reach the limits of the earlier deposits, so they are still exposed to view, and the degree of erosion of the surface of the older can be compared with that on the surface of the younger deposits. It is found that the older drifts have been so greatly eroded and are so ramified by drainage lines that no lakes or undrained basins remain on them, while the younger drift deposits have numerous lakes and undrained basins and also large, poorly drained areas which the streams have not yet reached. It is because they are not covered by the latest drift that Rock and Pipestone counties in southwestern Minnesota, and Goodhue, Dodge, Wabasha, Olmsted, Winona, Fillmore, and Mower counties in southeastern Minnesota have no lakes and basins such as characterize neighboring counties that were covered by that drift.

The invasions of the ice into Minnesota not only took place at different times, but have come from more than one direction at about the same time. In the earlier invasions the greater part of the state was covered by ice coming from Manitoba as shown by limestone fragments and pebbles derived from rock formations of that country which are imbedded in the lower part of the drift over all of the state except its northeast part. The movements in the closing stage of the glacial epoch were more largely from the northeast, but more than half of the state was invaded from the northwest. The ice sheets were as follows: 1. *The Superior lobe of the Labrador ice sheet,* an extension of ice southwestward from the Superior basin nearly to Mille Lacs Lake; 2. *The Patrician ice sheet,* with southward movement from the highlands north of Lake Superior across eastern Minnesota to points a little beyond St. Paul;

A. A GRAVEL OUTWASH IN LAKE COUNTY

B. GRAVEL IN BEACH OF LAKE AGASSIZ. PHOTOGRAPH BY D. W. JOHNSON

3. *The Keewatin ice sheet,* which moved southward through Manitoba and across western Minnesota. After the melting away of the ice that came from the northern highlands, the Keewatin ice sheet extended over some of the ground that ice had vacated. It crossed the Mesabi Range into the St. Louis basin, and also moved northeastward from near Minneapolis into Wisconsin. This advance over earlier drift deposits is known from the presence of a thin deposit of clayey and limy drift containing rock material brought from Manitoba which covers the drift that was deposited by ice coming from the highlands northwest of Lake Superior. The drift from these highlands together with that from the Lake Superior basin forms the stony red drift of eastern Minnesota, while that from Manitoba forms the clayey and limy gray drift which covers almost all of the remainder of the state.

That the ice mass moved in different directions at different times in certain parts of the state is further shown by striations or ice markings on the surfaces of the rock ledges. In the district east and south of the Lake of the Woods a set of glacial grooves or ice markings bears west of south, while a newer set crosses them in an eastward or southeastward direction. The older set was formed by ice moving into Minnesota from the highlands that lie between Lake Superior and Lake Winnipeg, while the younger set was formed by ice moving into the state from Manitoba. In North Minneapolis there are rock ledges on which the glacial grooves have three courses; first, a southeastward course at the time when the old gray drift which came from the northwest was brought in; second, a southward course at a time when the red drift which came from the north was deposited; third, an eastward course at the time when the ice from the northwest advanced over land that had been vacated by the ice which deposited the red drift.

GLACIAL LAKE FEATURES

Minnesota contains parts of the beds of two large glacial lakes: Lake Duluth, which occupied the western part of the Superior basin, and Lake Agassiz which occupied the Red River basin. Lake Duluth covered a narrow strip along the shore of Lake Superior and extended a few miles beyond the west end of Lake Superior into eastern Carlton County, Minnesota. Its highest stages were 500 to 700 feet above the present surface of Lake Superior, there being an increasing height toward the northeast corner of the state. Lake Agassiz extended as far south as Lake Traverse, and thence it discharged past Brown Valley to the Minnesota. Its border is only from 20 to 30 miles east from the North Dakota-Minnesota line from Lake Traverse northward to Polk County. About 20 miles east-southeast of Crookston it makes an abrupt eastward turn

and continues eastward past the south side of Red Lake and on across Koochiching County into St. Louis County as far as the valley of Little Fork River. It then turns northward and enters Canada from northeastern St. Louis County. There were several islands in it in northern St. Louis County.

Preceding the development of the large glacial Lake Agassiz there was a temporary ponding of waters in front of the ice in Koochiching, Itasca, and St. Louis counties at a level higher than that of Lake Agassiz, and a discharge of the waters southward across the Mesabi Iron Range into the St. Louis basin along the course of the Embarrass River. With the melting back of the ice border this lake became merged with Lake Agassiz, and its waters then discharged into the Minnesota valley.

There were also two noteworthy temporary lakes in northeastern Minnesota which were not held up by ice barriers, but instead by land barriers along their outlets. When these were cut away the lakes became drained. One of these, named Lake Aitkin by Upham, occupied the plain bordering the Mississippi in Aitkin County and extended a short distance into eastern Crow Wing County. It was drained by the erosion of the Mississippi valley at its lower end just above Brainerd. The other lake, named Lake Upham by Winchell, occupied a considerable part of the St. Louis basin in western St. Louis County. It was drained by the erosion of the St. Louis valley below Floodwood.

Prominent features of the two great glacial lakes, Lake Agassiz and Lake Duluth, are the beaches or ridges of sand and gravel washed up along their shores. The shores of Lake Agassiz stand high and dry above the flat parts of the lake bed between or below them and form excellent lines for highways. For this reason much of the pioneer settlement and travel was along these ridges. They generally stand from 5 to 10 feet above the bordering plains and occasionally from 15 to 20 feet. On the inner or lakeward side they are generally more prominent than on the outer or landward side. This is due in part to the original slope toward the center of the lake, but there is also a tendency for a lake to eat back into the bordering land and throw its coarser material up on the edge of the plain outside; at the same time the fine material is carried in suspension from the shore into the deeper water.

The levels of these glacial lakes were lowered from time to time, partly by the cutting-down of the outlets and partly by an uplift of this region which caused the water to fall away where the land rose. There was also a change of outlet in Lake Agassiz from the southern end to the northern and in Lake Duluth from the southward outlet into the St. Croix River to an eastward outlet into the Lake Huron basin. As a result shore lines were formed at various levels on the slopes of the

A. ESKER BETWEEN LAKES IN EASTERN LAKE COUNTY. PHOTO BY A. H. ELFTMAN

B. INTERIOR STRUCTURE OF AN ESKER IN LAKE COUNTY. PHOTO BY A. H. ELFTMAN

old lake beds. Because of the gradual lowering of the water level the greater part of the beds of these glacial lakes has at some time been subjected to wave action. This has produced a widespread pebbly coating which is a concentrate from the washing of the surface of the bowlder clay and the carrying-away of its finer material. Where the bowlder clay was sandy, the sand as well as stones remain, but where it was clayey there is often a clear bed of pebbles a few inches in depth covering the clayey till subsoil. The deep part of Lake Agassiz along the borders of Red River received nearly all the fine sediment which was washed out from the till at higher levels. This forms the bulk of the rich black clay and clay loam of the Red River basin. At its eastern border, fifteen to twenty-five miles from Red River, there is a transition to sand. This is succeeded within two to five miles east by stony sandy deposits which seem to be a glacial material worked over by the lake.

GENERAL SOIL CONDITIONS

Soil is composed of materials derived from the subsoil and mixed with organic matter. Subsoil is the weathered and disintegrated top of the underlying geological formation. For its qualities and composition the soil of a given region therefore depends quite closely upon the nature of the geological formations there exposed. In Minnesota the land mantle of glacial and lake deposits affords a well-mixed and rich supply of materials suited for soil-making. This is particularly true where it consists of till or bowlder clay in which all classes of material are loosely but thoroughly mixed. This contrasts with soils in which there is too much uniformity and which, when of water-washed sand or gravel, are often deficient in fine material. On the other hand, the loess and the lake silts, though of somewhat uniform texture, make rich soils because of the variety of finely divided minerals which they contain.

The soil and its productiveness depends largely upon the drainage conditions. A soil of clay or clay loam over gravel or loose sand suffers in time of deficient rainfall, while in wet seasons a soil resting upon heavy clay may be drowned out unless surface drainage is perfectly adjusted. For this reason the geologic formation underlying a soil is of great importance. Soil underlaid by limestone, by loess, or by a till consisting of a light clay, or a heavy loam will stand great variation in rainfall and still be highly productive. In some parts of the state the surface drainage is naturally well developed, while in other parts it needs to be greatly supplemented by tile draining or surface ditching.

In the Driftless Area the drainage on the uplands is everywhere complete, for nearly every acre slopes toward some drainage line. In the old drift also there are few undrained areas and tiling or surface ditching

is seldom necessary. In the young drift there are many basins, and undrained depressions and drainage lines are not well distributed over the surface. Except, therefore, where the material is loose enough for the rainfall to be absorbed completely the young drift areas need considerable ditching and tiling. In the bed of Lake Agassiz, although basins and depressions are rare, there are wide areas where the surface is very flat and extensive and systematic tiling or ditching is required to keep the land from being flooded.

VEGETATION

The condition of the soil depends to some degree upon the character of the vegetation which has covered it. In prairie districts there is a more uniform exposure to weathering agencies than in forested districts and consequently a more uniform soil is developed on a given deposit. On the whole, leaching of lime seems to be less rapid on prairies than in forests so that in the newer drift limestones are often present at the surface in prairies, but in the forested areas limestones are usually dissolved out to a depth of some inches and often to some feet from the surface. On the older drift the limestone is generally removed to a depth of several feet both in prairie and forest, but the leaching is perceptibly deeper in the forested areas. The rate of erosion and removal of soil is more uniform in prairie than in forested tracts. It takes more force to dislodge the trees than the grassy vegetation on hillside slopes, and erosion in the forests is likely to become concentrated in occasional gullies, whereas on prairies there are many small channels developed on every hillside which serve to break it down rapidly. On the whole, therefore, erosion is greater but leaching is less in prairie than in forested areas.

The forests occur only on protected slopes in much of southern Minnesota and are absent from such slopes in much of the western part of the state (Figure 3). In the central and northeastern parts they cover plains or uplands as well as valley slopes. The muskegs, which have a scanty forest growth, are developed chiefly in the northern half of the state and chiefly within the forested area.

WEATHERING

There are parts of the newer drift in which fresh material is close to the surface so that they can scarcely be said to have a subsoil different from the drift sheet as a whole. There are also places on valley slopes in the older drift where unweathered material is close to the surface, because erosion keeps pace with the weathering of the drift. At most places, however, the older drift has a mantle of weathered material several feet in thickness, while that of the younger drift is only one or two

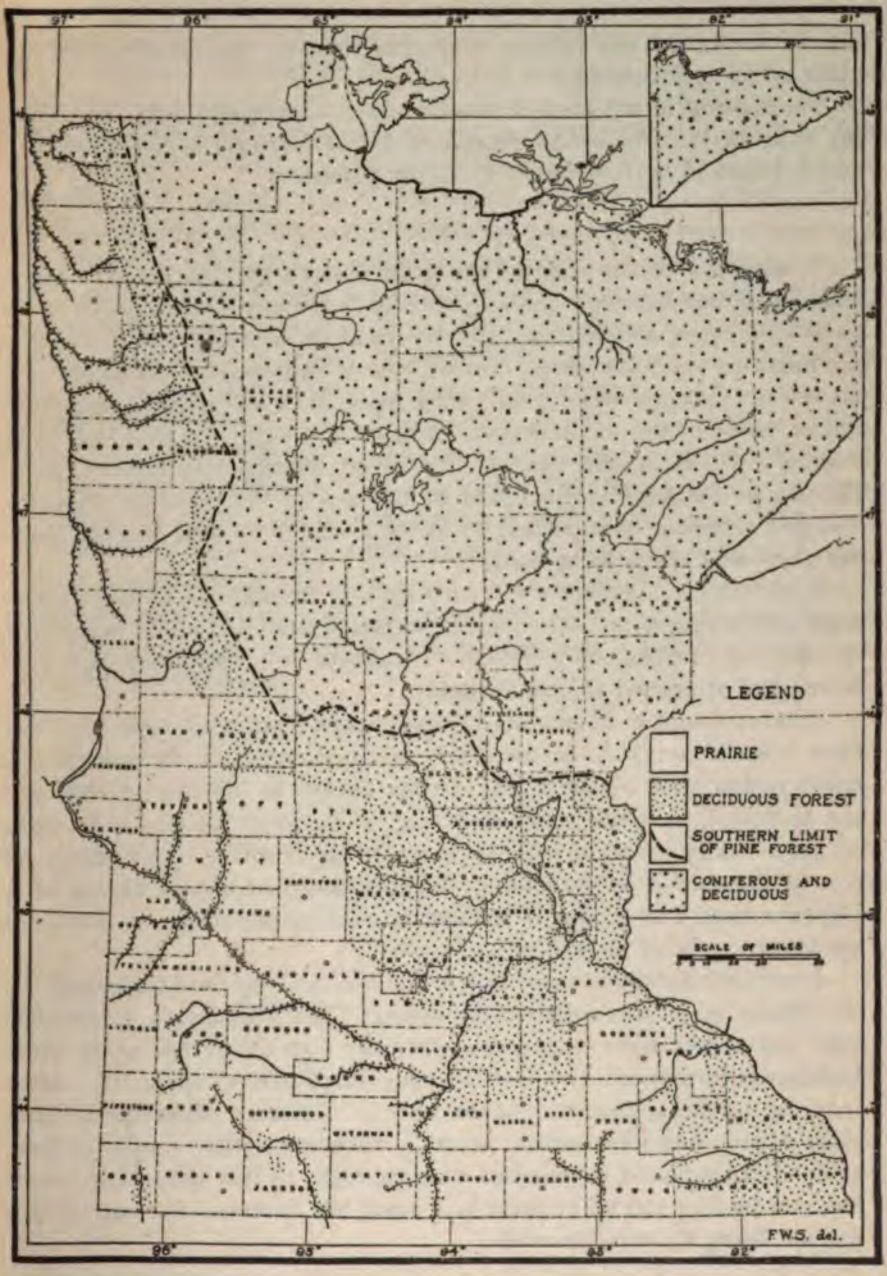


FIGURE 3. MAP OF MINNESOTA SHOWING DISTRIBUTION OF FOREST AND PRAIRIE. (AFTER MAP BY WARREN UPHAM AND BY FREDERIC K. BUTTERS)

feet thick. In this the feldspar and other minerals are disintegrated and made ready for plant food.

Weathering in the loess-covered areas is moderately deep, as it is in the older drift. The entire deposit of loess, however, is of fine texture and is found to be very fertile from top to bottom.

LIME

While most of the soils of the northwestern part of the state seem abundantly supplied with lime, it is probable that some of the more sandy ones would give a sufficiently greater yield of certain crops to make it profitable to purchase some form of lime if this could be obtained at a low price. Usually when a soil needs lime, it is advisable to apply one ton or more of ground limestone or marl per acre. If this has to be shipped any considerable distance, the freight charges may greatly exceed the cost of the material on board of the cars at the point of shipment. For this reason it is important to locate a supply as near as possible to the place where it is to be used.

Lime occurs abundantly in two forms in Minnesota: as bog-lime or marl, and as limestone. The marl is unconsolidated and easily pulverized. It needs no crushing or grinding. Limestone is consolidated and must be crushed or ground for use on fields.

Marl is found in Minnesota in many lakes and under some bogs that have been lakes. It is of most frequent occurrence in the central and north central part of the state. It lies always in low wet ground and can be found, as a rule, only by boring or ditching. It is a soft, white or gray, chalky material. Since it needs no crushing or grinding, the cost of the marl is in the finding, ditching and draining, or drying of it. Deposits from 1 to 10 feet in thickness and covering from 1 to 100 acres are known to be of common occurrence.

Limestone formations outcrop in the bluffs along the Mississippi and its tributaries in southeastern Minnesota. The formations lie horizontally and are of wide extent, or practically continuous for many miles. Limestone formations 100 feet or more thick extend along the valleys from the southeastern corner of the state to Stillwater, Minneapolis, Mankato, Austin, and intermediate points. An inexhaustible supply of limestone is easily found in outcrops that are high, so that quarrying, crushing, and loading can all be done in a down-hill direction, the cost of production being thereby lessened.

EFFECT OF FIRES

There are large areas in Minnesota which have been swept by forest fires, and these fires have destroyed much of the accumulated leaf mold.

In sandy areas the destruction of the leaf mold may have reduced somewhat the productiveness of the land, for the leaf mold acts as a mulch to prevent the drying out of the soil. But in clayey areas there seems to have been very little reduction of the fertility. The leaf mold in such places, however, when turned under has a beneficial effect in loosening the stiff clay. A large area of clay land in the Little Fork drainage basin in St. Louis and southeastern Koochiching counties was burned over some fifty or more years ago, according to statements of the Indians, and the leaf mold was almost completely destroyed. A heavy growth of poplar has sprung up on the drier parts instead of the mixed hardwood that had occupied the land, while the wet areas have a fresh stand of spruce (See Plate XIVA). This district is being rapidly cleared and is producing exceptionally good crops. The forest fire near Hinckley in Pine County, which occurred about twenty-five years ago, swept over an area chiefly of till much of which is loose-textured. This had a similar effect in changing the forest from mixed hardwood and pine to poplar. This area is now one of marked agricultural fertility adapted to a variety of crops. The principal damage by fire in this state, both past and prospective, seems to be in the destruction of peat in the bogs. In such cases there is not only the loss of a valuable fuel, but the land is left in a rough state ill-suited for cultivation.

CHAPTER II

CLIMATIC CONDITIONS OF MINNESOTA

By U. G. Purssell

Director of the Minnesota Section of the United States Weather Bureau

INTRODUCTION

The agriculture of any region is controlled by its climate. In some parts of the world temperature is the main factor in determining the limits of growth of certain kinds of crops; in others it is rainfall, and in still others it is the amount of sunshine. All of these factors are important in influencing the crop yield even in districts where the general climatic conditions are satisfactory for the growth of plants. In Minnesota these elements are so favorable that a majority of the crops common to the temperate zone may be successfully grown, and a failure of all the important crops is very rare even over a small portion of the state.

Rainfall is an important factor for most crops in the state, because the proper amount of water in the soil at the critical period of development of the plant is necessary to produce a large crop. The length of the growing season also is important and probably no other factor in the study of climate from the standpoint of the agriculturist should be given more consideration. This is the key to an actual knowledge as to the possibilities of success or failure in the production of crops since in parts of the state crops are menaced by frost at some period of their growth, whereas sunshine and moisture seldom vary in Minnesota beyond safe limits.

The factors which determine the climate of any area are the relative distribution of land and water, the topography of the land surface, and the situation of the area in question with relation to the general movement of the cyclones and anti-cyclones.

The position of Minnesota at the center of North America gives it a climate that is largely continental. In continental climates the temperature extremes are greater and the humidity and rainfall generally less than at places near large bodies of water, such as border on the Atlantic, Pacific, and Gulf coasts of the United States. The effect of winds from great bodies of water is to equalize temperatures of lands near by and to lengthen materially the crop-growing season. This is particularly true of the country in the vicinity of Lake Superior, where the influence of that great inland sea in modifying the cold anti-cyclones

gives to that section a more equable climate than would otherwise obtain in that portion of the state. The summer temperatures are likewise modified and people from long distances inland in steadily increasing numbers are establishing summer homes about the lake, to which they are attracted during the hot summer months. There are more than 7,000 small lakes scattered throughout the state and these have a material local influence in modifying the heat of summer and give comfort to thousands of residents on their shores.

Monthly and annual reports of temperature, rainfall, snowfall, etc., have been published for a large number of regular and coöperative stations in Minnesota since 1895. Recently three special section reports have been issued by the United States Weather Bureau giving monthly and annual precipitation totals for all points in the state with a record of ten years or over, together with average temperatures and other data. In these reports the more important facts from all portions of the state are tabulated and the comparative climatic conditions of the different sections graphically shown.

GENERAL CLIMATIC CONDITIONS

Minnesota is in the path of a large proportion of the low-pressure areas which move across the United States from west to east. These areas move at an average speed of 600 miles in twenty-four hours and are preceded by southerly winds and higher temperature and followed by northerly winds and lower temperature. They are usually accompanied by cloudy weather and precipitation; each storm causing an average of from one to two rainy days as it crosses the state.

As there is an average of almost two of these storms each week with fair weather periods between, it follows that the changes in weather conditions are rather rapid. One or two days of stormy weather preceded by fair weather and followed by clearing and lower temperatures to be repeated in turn, make up the usual routine for the week. However, Minnesota is so far from the coast that damaging ocean storms lose much of their severity before reaching its borders.

The northwestern cold waves pass across the state and send their health-giving winds into all parts, and yet they are frequently not so severe as they are in some of the plains states in the same latitude or even farther south.

Temperature.—The average annual temperature of Minnesota for the period 1895 to 1913 inclusive, is 41.7°, as shown in Table I and graphically by Figure 4. The highest annual mean temperature, 43.9°, occurred in 1900, and the lowest, 39.9°, in 1912. The departure of the average temperature of any year from the normal may readily be deter-

FIGURE 4. MAP SHOWING MEAN ANNUAL TEMPERATURES OF MINNESOTA (DEGREES FAHRENHEIT)

mined by comparing the yearly average with the mean at the foot of the column.

Table I. Monthly and Annual Mean Temperature for Minnesota (Degrees Fahrenheit)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1895	.....	.....	.....	49.9	56.9	64.6	67.8	67.4	61.5	41.4	27.8	18.3	......
1896	12.3	17.9	21.4	44.5	60.9	66.5	69.9	67.9	54.3	42.4	18.0	20.3	41.6
1897	7.2	15.3	20.7	43.7	55.2	62.5	71.6	64.2	65.3	50.0	26.6	12.3	41.2
1898	18.3	16.4	30.3	43.5	55.6	67.0	69.8	66.9	60.6	42.9	26.6	11.9	42.2
1899	9.9	4.5	14.7	44.0	55.1	65.4	70.2	69.1	56.4	49.0	39.6	17.9	41.2
1900	18.4	5.2	23.4	49.5	59.9	66.8	68.8	74.3	58.2	55.1	25.4	18.6	43.9
1901	13.2	10.0	27.3	46.7	58.2	65.5	74.7	69.8	57.3	49.2	28.8	13.0	42.8
1902	15.9	15.5	34.0	42.6	57.0	61.3	69.7	65.2	55.2	47.1	33.3	12.6	42.6
1903	11.3	10.6	29.6	43.3	55.7	62.3	67.2	63.6	55.5	46.1	27.3	9.8	40.3
1904	4.5	2.3	24.8	38.8	55.4	63.2	66.0	64.9	57.4	47.4	36.7	16.7	40.1
1905	5.6	8.9	33.7	42.0	52.6	63.0	67.3	68.9	61.9	43.5	33.1	20.6	41.5
1906	17.0	13.8	20.6	47.9	53.7	63.7	68.3	68.7	63.3	45.7	30.7	15.9	42.0
1907	3.8	14.8	28.7	34.7	45.5	63.3	68.2	66.1	55.9	45.4	31.7	21.3	40.1
1908	16.4	17.9	26.4	45.2	53.9	62.5	69.4	65.5	64.2	47.0	33.8	17.5	43.4
1909	10.5	13.7	26.1	35.8	53.2	65.0	69.2	70.9	58.7	44.7	33.8	10.0	41.0
1910	11.8	7.5	41.7	48.0	51.6	67.8	70.6	65.8	58.4	50.8	25.3	14.7	42.8
1911	5.4	16.6	32.7	42.7	59.8	69.7	68.2	64.0	56.7	43.4	20.2	19.4	41.6
1912	—6.7	10.6	19.8	45.5	55.9	62.5	68.5	63.9	57.2	47.5	33.9	20.0	39.9
1913	7.2	8.6	20.4	46.4	52.7	67.4	67.3	69.2	58.6	42.7	36.9	26.1	42.0
1914	16.9	2.8	26.6	41.2	57.6	64.6	72.4	66.1	60.0	52.6	33.0	.....	......
Mean....	10.5	11.2	26.5	43.8	55.3	64.7	69.3	67.1	58.8	46.5	30.1	16.7	41.7

The coldest month is January, which has a mean temperature of 10.5°, although the average for February is only 0.7° higher. In a great many instances February has averaged colder than the preceding January. This condition occurred in the seven successive years from 1898 to 1904 inclusive. Average January temperatures are plotted on Figure 5.

July is the warmest month, with an average temperature of 69.3°, although in a few years the mean temperature for June or for August is higher than for July of the same year. Average July temperatures are plotted on Figure 6.

The highest summer mean, 70.0°, occurred in 1900 and 1901 (Table II). The coldest summer was that of 1903, with an average of 64.4°.

The warmest crop-growing season (April to September inclusive) of the eighteen years under discussion was in 1900, when the average was 62.9°, and the coldest was in 1907, with an average of 55.6°.

The warmest winter (December to February inclusive) was in 1907-8, when the mean temperature was 18.5°. The coldest was in 1903-4, with a mean temperature of 5.5°. Table II shows also the warmest and coldest spring and autumn.

In Figures 7 and 8 are shown the highest and lowest temperatures ever recorded in the various counties where records have been kept. From these figures it can readily be seen that the extreme range of temperature is from 107° at Grand Meadow and Milan, to —59° at Leech Lake Dam and Pokegama Falls. Temperatures above 100° have been recorded in all counties except those about the headwaters of the Missis-

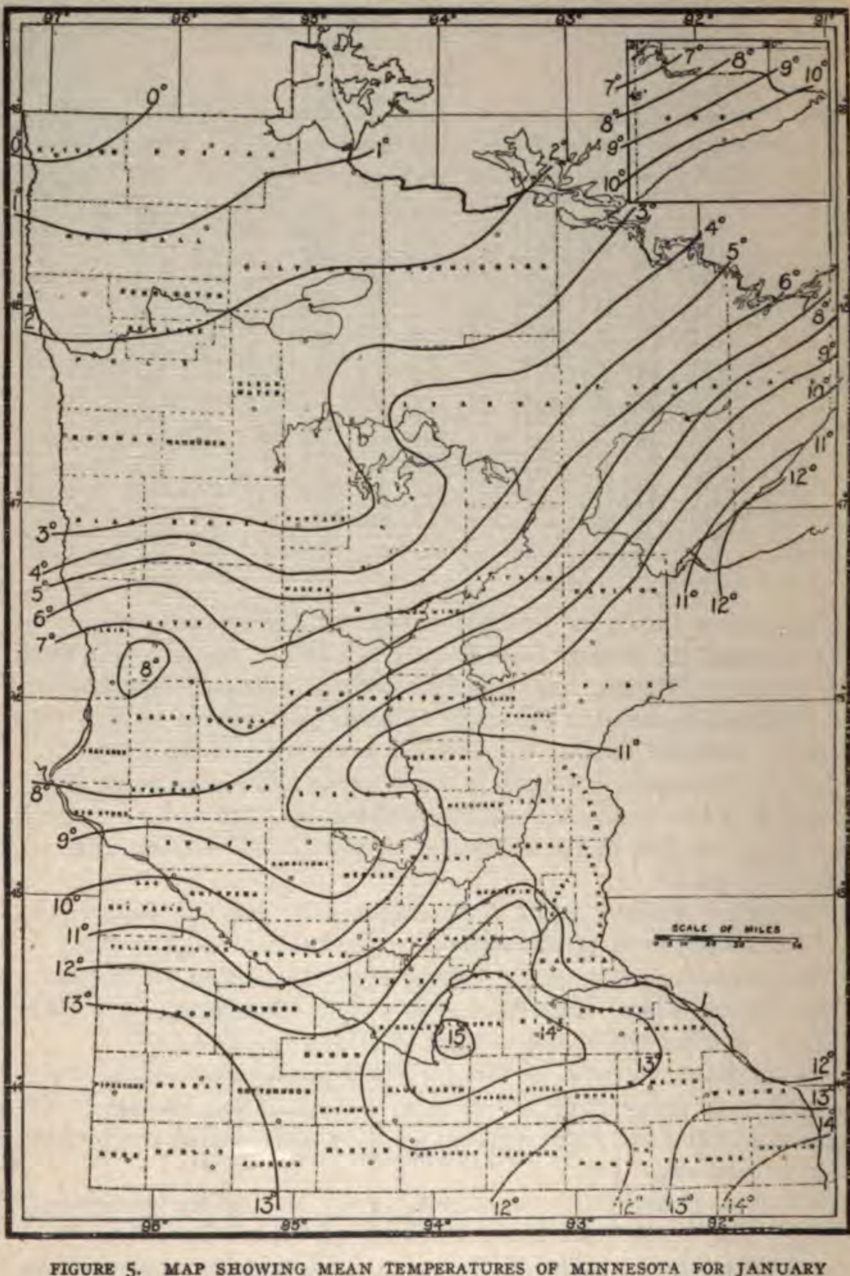


FIGURE 5. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JANUARY (DEGREES FAHRENHEIT)

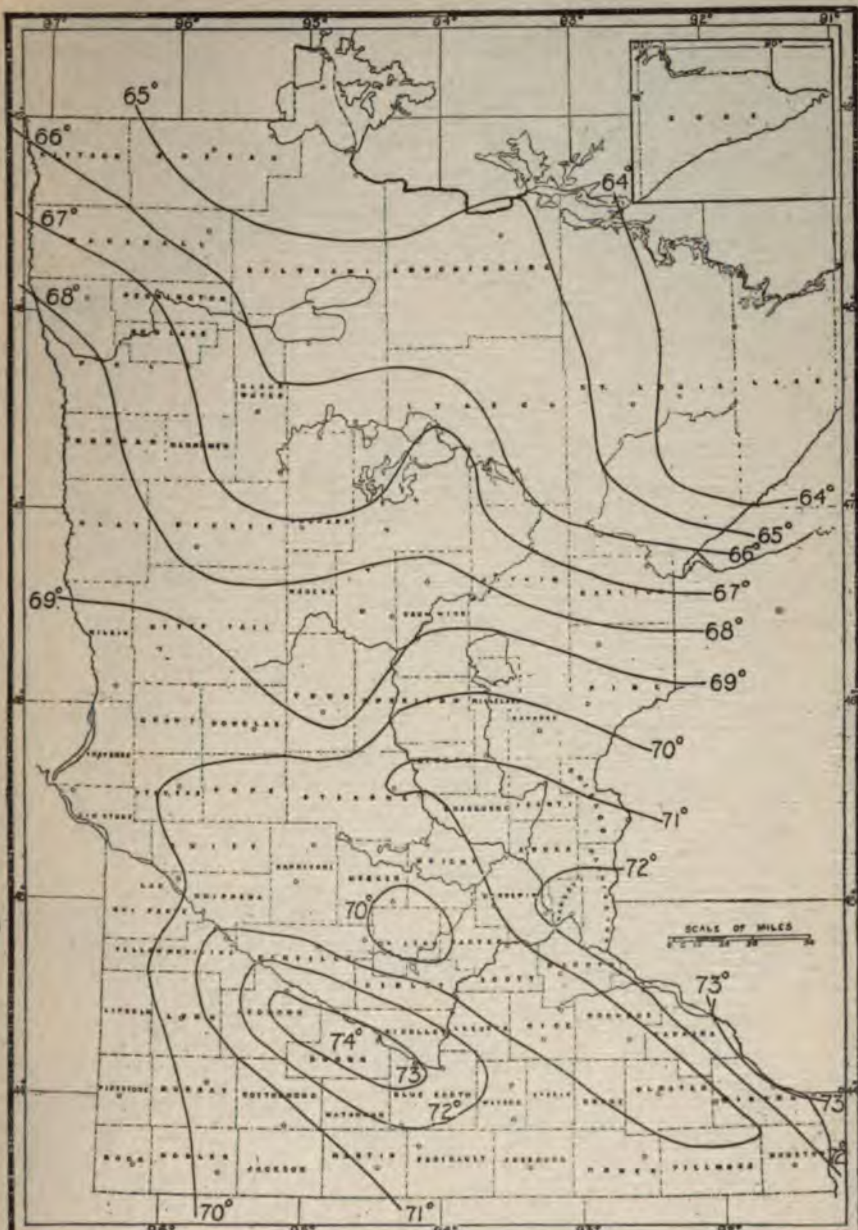


FIGURE 6. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

FIGURE 7. MAP SHOWING HIGHEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

FIGURE 8. MAP SHOWING LOWEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

sippi River, and in the country immediately bordering on Lake Superior. Temperatures of —40° have occurred in nearly all northern and central counties and in a few southern counties, but these great extremes do not occur frequently.

Table II. Seasonal Temperatures for Minnesota (Degrees Fahrenheit)

Year	Winter mean	Spring mean	Summer mean	Fall mean	April to Sept. inclusive (crop-growing season)
1895	....	....	....	....	61.4
1896	16.2	42.3	68.1	38.2	60.7
1897	14.3	39.9	66.1	47.3	60.4
1898	15.7	43.1	67.9	43.4	60.6
1899	8.8	37.9	68.2	48.3	60.0
1900	13.8	44.3	70.0	46.2	62.9
1901	13.9	44.1	70.0	45.1	62.0
1902	14.8	44.5	65.4	45.2	58.5
1903	11.5	42.9	64.4	43.0	57.9
1904	5.5	40.0	64.7	47.2	57.6
1905	10.4	42.8	66.4	46.2	59.3
1906	17.1	40.7	66.9	46.6	60.9
1907	11.5	36.3	65.9	44.3	55.6
1908	18.5	41.8	65.8	48.3	60.1
1909	13.9	38.4	68.4	45.7	58.8
1910	9.8	47.1	68.1	44.8	60.4
1911	12.2	45.1	67.3	40.1	60.2
1912	7.8	40.4	65.0	46.2	58.9
1913	11.9	39.8	68.0	46.1	60.3
1914	15.3	41.8	67.7	48.5	60.3
Mean	12.8	41.7	67.0	45.3	59.8

Frosts.—Although frosts have occurred in some portions of the state every month of the year, damaging temperatures are not to be expected during June, July, and August, and they are comparatively rare in the last half of May and the first half of September. Records of ten or more years are available from a large number of places in the state, of which charts have been constructed showing the average date of the last killing frost in spring and the first one in autumn. Using these dates as boundaries, we can mark the average beginning and ending of crop growth and determine the average length of the growing season. All of this information is graphically shown in Figures 9, 10, and 11. By reference to Figure 11 the influence of Lake Superior in lengthening the crop-growing season in its vicinity may be seen; while in the same latitude in the highlands of Hubbard, Becker, eastern Mahnomen, and Clearwater counties the season is twenty to thirty days shorter. The longest season, 160 days, obtains along the Mississippi River from Hennepin County to the southeastern corner of the state, and the shortest, 100 days or less, is in the region of the Mesabi and Vermilion Iron ranges.

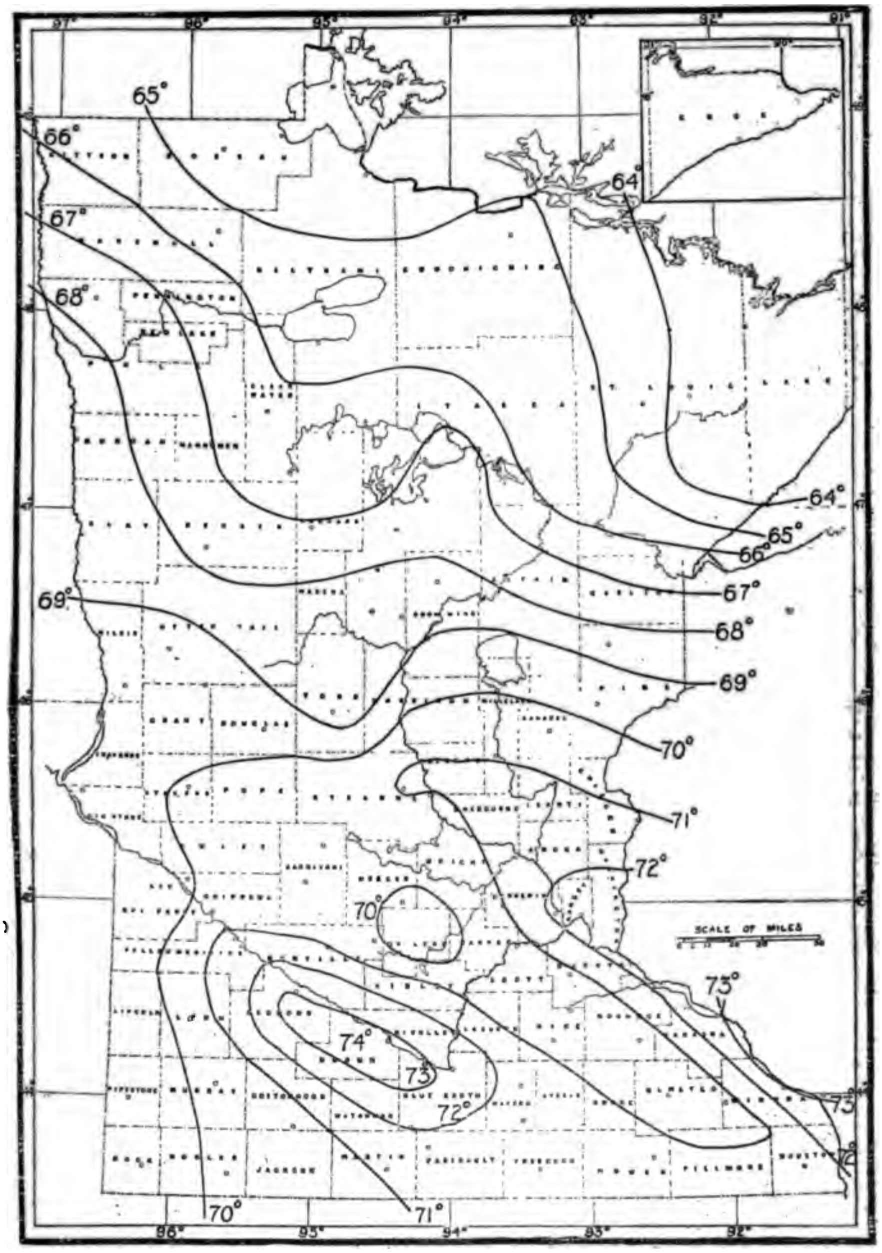


FIGURE 6. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

FIGURE 10. MAP SHOWING AVERAGE DATE OF FIRST KILLING FROST IN AUTUMN IN MINNESOTA

FIGURE II. MAP SHOWING NUMBER OF DAYS OF THE AVERAGE CROP-GROWING SEASON IN MINNESOTA

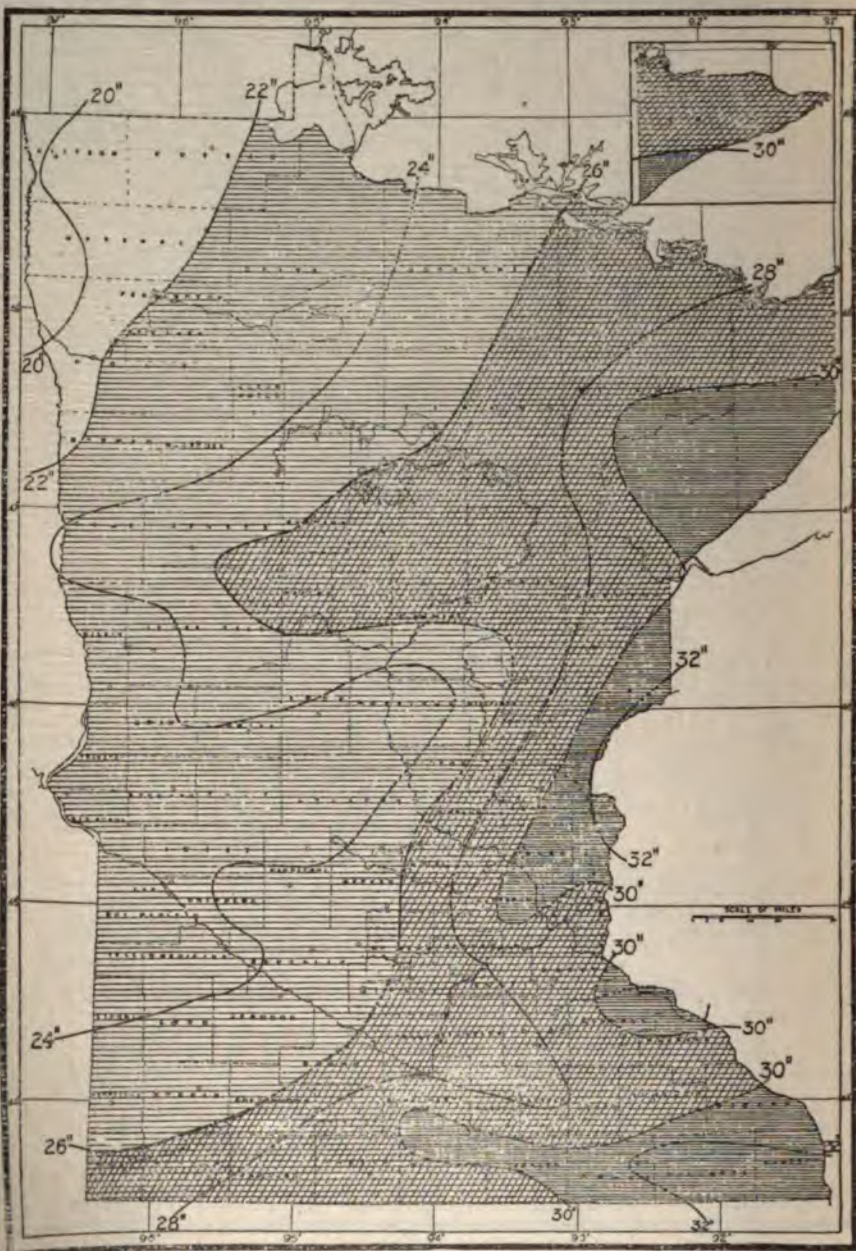


FIGURE 12. MAP SHOWING THE AVERAGE ANNUAL PRECIPITATION FOR MINNESOTA

Table III. Average Monthly and Annual Precipitation for Minnesota (in Inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Total April to Sept. incl.
1895	....	....	....	1.68	3.30	4.37	3.25	2.27	3.93	0.25	1.22	0.28	.....	18.80
1896	0.76	0.39	1.97	5.91	5.02	4.07	1.88	2.28	2.49	2.95	2.69	0.61	32.04	21.65
1897	1.77	1.21	2.07	1.55	1.38	5.40	6.62	2.54	1.89	1.55	0.53	0.38	27.23	19.38
1898	0.16	1.02	1.21	1.64	3.26	3.93	2.94	3.22	1.52	3.83	1.02	0.18	24.21	16.51
1899	0.60	0.78	1.58	1.49	4.46	6.36	2.84	5.35	1.47	3.22	0.63	0.95	30.14	21.97
1900	0.48	0.56	1.30	1.47	0.90	1.71	5.48	6.44	6.55	3.85	0.62	0.51	29.79	22.55
1901	0.38	0.40	1.68	1.73	1.41	5.81	3.33	2.21	4.34	1.86	0.78	0.57	24.26	18.83
1902	0.44	0.67	0.92	1.67	5.10	3.32	4.76	4.35	2.23	1.93	1.57	1.79	29.46	21.43
1903	0.45	0.59	1.75	2.82	5.37	1.96	5.11	4.65	5.63	3.13	0.35	0.84	32.85	25.54
1904	0.39	0.62	1.51	1.72	2.43	4.26	3.96	2.77	3.14	3.50	0.14	0.82	29.65	18.28
1905	0.65	0.55	1.21	1.46	5.54	6.41	4.12	4.36	3.45	2.53	2.64	0.15	33.10	25.34
1906	1.15	0.27	1.20	1.72	5.58	4.55	2.93	4.66	3.73	2.28	1.82	0.91	31.66	23.17
1907	1.17	0.58	0.94	1.01	2.14	4.31	3.57	4.11	3.48	1.31	0.57	0.57	24.03	18.62
1908	0.31	1.11	1.47	2.55	6.31	6.35	3.21	2.07	2.41	1.91	1.18	0.79	29.49	22.90
1909	1.32	1.31	0.54	1.89	3.36	3.53	3.84	5.54	3.16	1.56	2.68	1.54	29.27	20.32
1910	0.83	0.45	0.27	1.54	1.58	1.39	1.94	2.35	2.45	0.97	0.52	0.44	14.73	11.25
1911	0.81	0.88	0.63	1.88	3.48	3.79	3.61	4.27	3.35	3.93	1.12	1.35	29.10	20.38
1912	0.40	0.21	0.45	2.04	4.13	1.66	4.30	3.97	3.03	0.97	0.36	0.93	22.45	19.13
1913	0.33	0.44	1.27	1.87	3.53	3.08	5.56	2.79	3.33	2.58	0.66	0.05	25.49	20.16
1914	0.81	0.44	1.12	2.41	2.89	8.34	2.48	3.97	3.08	2.00	0.38	....	.....	23.77
Mean	0.70	0.66	1.22	2.00	3.56	4.18	3.79	3.66	3.23	2.31	1.07	0.71	27.72	20.33

Precipitation.—The annual average precipitation of the state as a whole for a period of eighteen years, 1896 to 1914 inclusive, is 27.72 inches, and for the crop season, April to September inclusive, for twenty years, 1895 to 1913, is 20.33 inches. The monthly, seasonal, and annual averages for this period are shown in Table III. The year with the greatest annual rainfall was 1905, when the total was 33.10 inches. The driest year was 1910 with 14.73 inches. In that year the rainfall during the crop-growing season was 11.25 inches.

Table IV. Average Monthly and Annual Precipitation by Drainage Districts

Watersheds	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake Superior..	0.88	0.88	1.41	2.05	3.50	4.19	4.21	3.73	4.18	2.80	1.45	1.13	30.40
Rainy River....	0.94	0.94	1.42	1.96	3.10	4.04	3.76	3.32	2.98	2.08	1.46	0.98	26.98
Red River.....	0.55	0.56	0.98	1.84	2.85	3.83	3.34	3.12	2.32	1.55	0.72	0.56	22.22
Mississippi (above St. Croix)....	0.73	0.70	1.23	2.16	3.42	4.13	3.61	3.57	3.00	2.29	1.05	0.73	26.63
St. Croix and Mississippi (below St. Croix)....	0.92	0.95	1.49	2.37	4.01	4.46	3.72	3.69	3.72	2.73	1.36	1.13	30.57
Minnesota River	0.79	0.73	1.19	2.30	3.52	4.18	3.34	3.44	2.63	2.11	1.02	0.79	26.04
Big Sioux and Des Moines Rivers	0.50	0.54	1.13	2.09	4.00	4.39	3.49	3.58	2.79	2.07	0.94	0.63	26.15
State.......	0.76	0.75	1.25	2.18	3.53	4.19	3.55	3.50	3.02	2.24	1.09	0.84	26.90

June is the wettest month with an average rainfall of 4.18 inches, and July is next with 3.79 inches. The lowest monthly rainfall is that of February with an average of 0.66 inch. The greatest rainfall in one month for the state as a whole was 8.34 inches in June, 1914. The lowest rainfall for any month was .05 inch in December, 1913.

The geographic distribution of annual and monthly precipitation is

FIGURE 13. DIAGRAM SHOWING COMPARATIVE MONTHLY DISTRIBUTION OF PRECIPITATION IN MINNESOTA. LETTERS INDICATE MONTHS, BLACK COLUMNS INDICATE INCHES OF RAINFALL IN EACH MONTH AT STATION NAMED

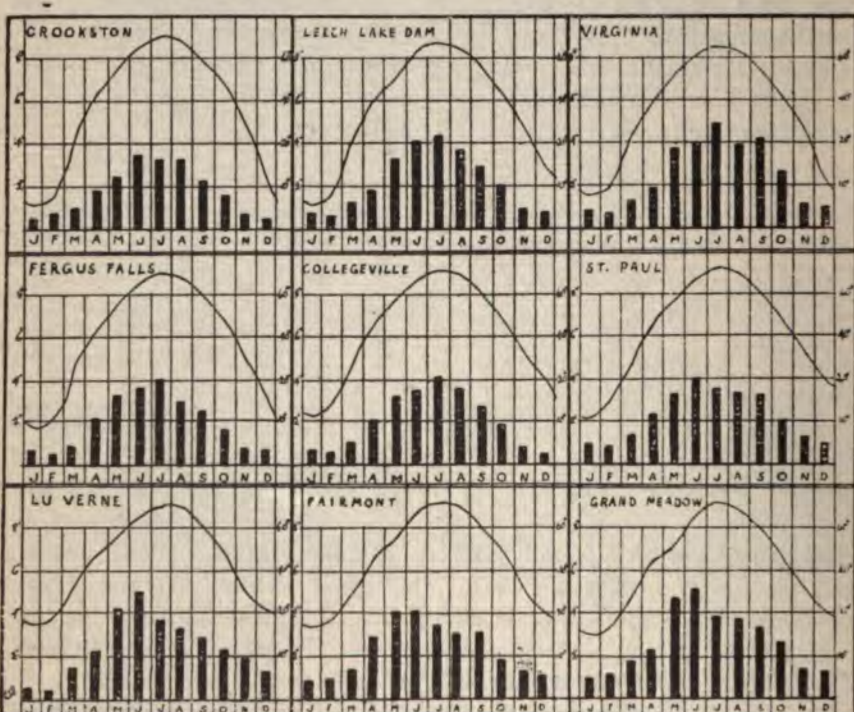


FIGURE 14. DIAGRAM SHOWING MEAN MONTHLY RAINFALL AND MEAN MONTHLY TURE AT SEVE IONS IN MINNESOTA. MONTHS ARE INDICATED BY T EATEST RAINFALL IS IN THE GROWING SEASON.

FIGURE 11. MAP SHOWING NUMBER OF DAYS OF THE AVERAGE CROP-GROWING SEASON IN MINNESOTA

FIGURE 13. DIAGRAM SHOWING COMPARATIVE MONTHLY DISTRIBUTION OF PRECIPITATION IN MINNESOTA. LETTERS INDICATE MONTHS, BLACK COLUMNS INDICATE INCHES OF RAINFALL IN EACH MONTH AT STATION NAMED

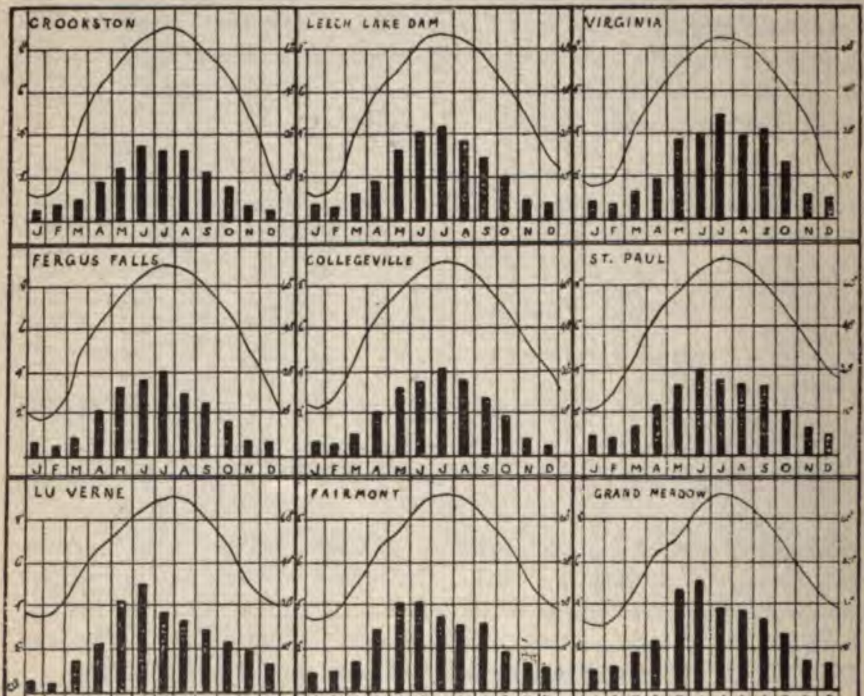
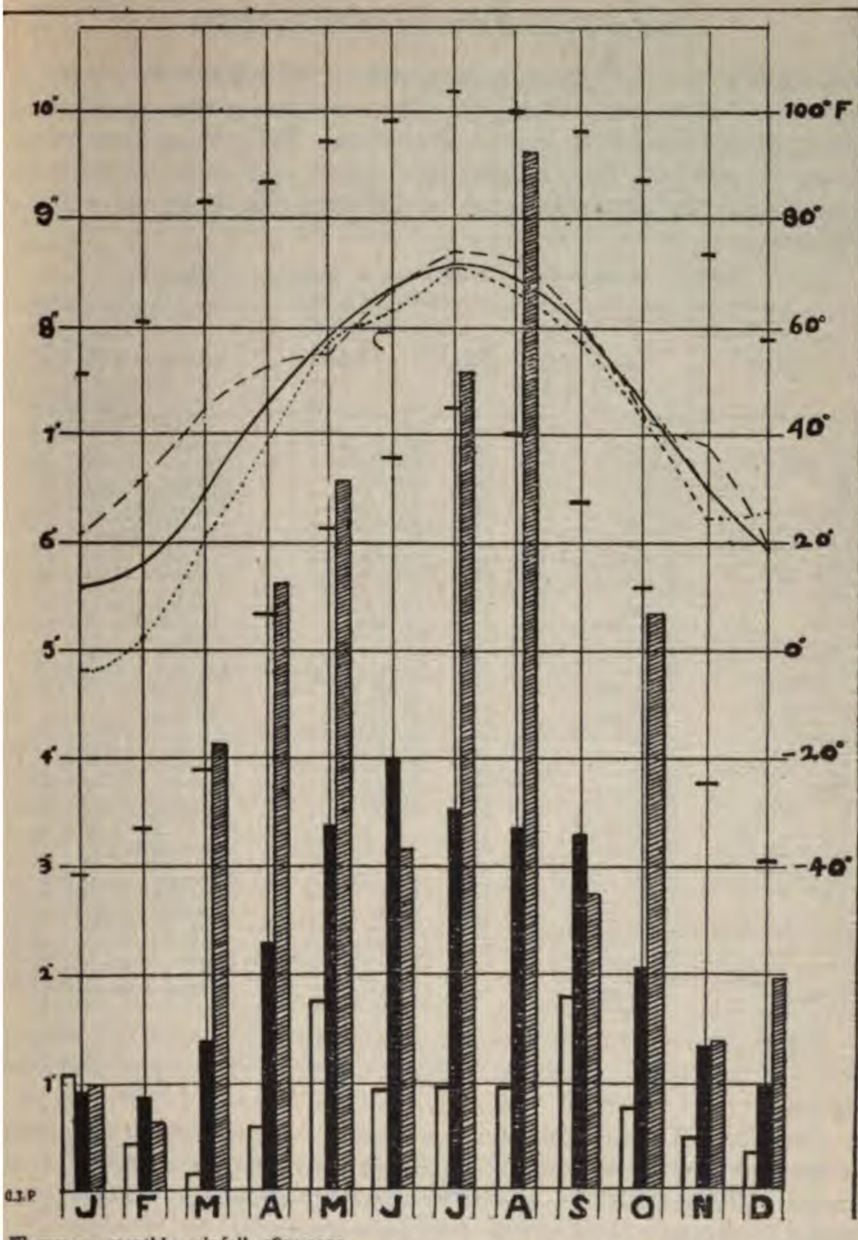


FIGURE 14. DIAGRAM SHOWING MEAN MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURE AT SEVERAL STATIONS IN MINNESOTA. MONTHS ARE INDICATED BY *THEIR FIRST LETTERS*. THE GREATEST RAINFALL IS IN THE GROWING SEASON.



=mean monthly rainfall, 1873-1913.
=monthly rainfall of year of greatest rainfall recorded, 1849.
=monthly rainfall of year of least rainfall recorded, 1910.
Solid curve=mean monthly temperature, 1871-1913.
Dotted curve=mean monthly temperature for year of lowest annual temperature recorded, 1875.
Dashed curve=mean monthly temperature for year of highest annual temperature recorded, 1878.
Horizontal dashes show absolute maximum and minimum temperatures recorded.

FIGURE 15. DIAGRAM SHOWING RAINFALL AND TEMPERATURES (DEGREES FAHRENHEIT) AT ST. PAUL, MINNESOTA FROM 1837-1913. MONTHS ARE INDICATED BY THEIR FIRST LETTERS

graphically shown in Figures 12 to 14, and for the stations having ten or more years of record in Table V. Table IV shows the monthly and annual distribution in the various watersheds. From these illustrations it may be seen that the precipitation is about one-fourth to one-third greater along the eastern boundary of the state than along the western boundary.

Table V. Average Annual Precipitation in Minnesota by Stations

Stations	County	Length of record	Average annual precip.	Station	County	Length of record	Average annual precip.
		Yrs.	Inches			Yrs.	Inches
Albert Lea	Freeborn	21	29.90	Montevideo	Chippewa	22	23.50
Alexandria	Douglas	25	23.74	Moorhead	Clay	31	24.92
Angus	Polk	10	19.00	Morris	Stevens	27	23.23
Ashby	Grant	14	24.47	New London	Kandiyohi	18	23.62
Beardsley	Bigstone	16	23.79	New Richland	Waseca	10	29.91
Bird Island	Renville	22	24.23	New Ulm	Brown	32	27.74
Blooming Prairie	Steele	13	27.45	Northfield	Rice	12	29.92
Caledonia	Houston	19	33.70	Osceola, Wis.	Polk	21	32.13
Collegeville	Stearns	19	22.76	Park Rapids	Hubbard	22	25.71
Crookston	Polk	22	22.41	Pembina, N. D.	Pembina	14	19.79
Detroit	Becker	16	25.96	Pine River Dam	Crow Wing	25	27.52
Duluth	St. Louis	41	29.93	Pipestone	Pipestone	12	24.18
Fairmont (near)	Martin	25	28.20	Pokegama Falls	Itasca	25	27.62
Faribault	Rice	14	28.00	Red Wing	Goodhue	16	31.71
Farmington	Dakota	24	29.29	Redwood Falls	Redwood	13	24.65
Fergus Falls	Otter Tail	24	23.24	Reeds Landing	Wabasha	16	29.31
Flandreau, S. D.	Moody	22	24.57	St. Charles	Winona	21	30.68
Fort Ripley	Crow Wing	43	25.25	St. Cloud	Sherburne	19	27.68
Glencoe	McLeod	15	26.64	St. Paul	Ramsey	41	28.68
Grand Meadow	Mower	24	32.59	St. Peter	Nicollet	18	27.89
Grantsburg, Wis.	Burnett	21	33.06	Sandy Lake Dam	Aitkin	19	26.47
Hallock	Kittson	13	21.37	Shakopee	Scott	15	28.85
Halstad (Ada)	Norman	16	21.27	Tonka	Hennepin	13	30.54
International Falls	Koochiching	10	25.75	Tower (Ely)	St. Louis	10	28.17
La Crosse, Wis.	La Crosse	40	31.17	Two Harbors	Lake	18	30.56
Leech Lake Dam	Cass	24	27.00	University, N. D.	Grand Forks	20	20.47
Long Prairie	Todd	20	25.17	Virginia (Mt. Iron)	St. Louis	18	30.74
Luverne	Rock	15	27.60	Wabasha	Wabasha	17	30.54
Lynd	Lyon	19	25.43	Wahpeton, N. D.	Richland	20	23.67
Mankato	Blue Earth	14	27.50	Willmar	Kandiyohi	10	25.54
Mapleplain	Hennepin	17	31.11	Willow River	Pine	10	29.98
Milaca	Mille Lacs	13	27.27	Winnebago	Faribault	14	30.58
Milan	Chippewa	18	24.49	Winnibigoshish	Itasca	25	25.66
Milbank, S. D.	Grant	21	22.69	Winona	Winona	16	29.63
Minneapolis	Hennepin	21	29.31	Worthington	Nobles	17	28.24

Figure 14 makes an interesting comparison of monthly and annual values of both temperature and rainfall at certain selected representative stations.

Snowfall.—The snowfall averages from 24 to 54 inches. It is lightest in the southwest portion of the state and heaviest on the Mesabi Iron Range. The monthly and annual averages are shown in Table VI, arranged according to sections and drainage districts.

Winds.—The prevailing winds are from the northwest over most of the state. The monthly and annual prevailing directions are shown for a large group of stations in Table VII. The average hourly wind velocity is shown for six regular Weather Bureau stations and three special stations in Table VIII.

Relative humidity.—The average annual humidity for the state is

Table VI. Average Snowfall

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Yrs.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake of the Woods Group—														
Red River Valley Group—							0	0	0	0.2	0.4	8.4	8.2	50.5
Tower	9	9.0	8.6	10.9	4.2	0.6								
St. Vincent-Pembina	14	8.4	5.1	6.9	5.2	0.7	0	0	0	0.1	0.7	5.7	6.4	39.2
Crookston	14	6.3	6.7	8.8	3.2	2.0	0	0	0	T.	0.4	4.5	5.7	35.8
Moorhead	17	7.6	6.7	8.9	4.9	0.3	0	0	0	0.1	1.0	6.9	6.8	43.7
Upper Mississippi River Valley Group—														
Park Rapids	14	9.0	6.5	9.1	5.4	0.9	0	0	0	0.2	1.4	7.4	6.3	46.2
Lake Winnibigosish	14	8.6	6.5	9.9	3.3	0.8	0	0	0	T.	1.0	7.8	7.8	45.7
Sandy Lake Dam	14	9.0	9.5	10.6	3.6	0.7	0	0	0	0.2	1.1	7.4	7.4	49.4
Lake Superior Group—														
Mt. Iron	13	9.9	7.8	11.2	3.9	1.1	0	0	0	0.1	0.8	8.1	11.6	54.4
Duluth	25	10.3	9.1	11.1	4.0	1.0	0	0	0	0.1	0.3	8.2	8.7	52.8
Lower Mississippi River Valley Group—														
La Crosse, Wis.	15	8.4	8.7	6.6	1.4	T.	0	0	0	T.	0.1	3.9	8.9	37.1
Grand Meadow	14	8.0	9.8	9.9	3.1	0.4	0	0	0	T.	0.3	5.3	9.3	46.1
St. Charles	9	7.7	9.4	9.5	2.4	0.2	0	0	0	0	0.1	4.3	9.3	42.9
Red Wing	8	8.0	5.6	4.4	1.8	0.2	0	0	0	T.	0.3	1.5	7.1	28.9
St. Paul	24	7.7	6.2	8.8	3.6	0.2	0	0	0	T.	0.2	4.7	5.7	37.1
Lower Minnesota River Valley Group—														
Shakopee	14	7.7	8.1	7.8	1.9	T.	0	0	0	T.	0.4	3.0	4.6	33.5
St. Peter	13	5.5	6.1	7.1	0.7	T.	0	0	0	0	0.4	1.4	4.0	25.2
Winnebago	10	6.5	7.5	6.3	1.0	T	0	0	0	T.	0.3	2.3	6.5	30.4
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8.3	8.6	9.5	4.0	0.2	0	0	0	T.	0.3	4.5	6.4	42.4
Collegeville	14	6.7	5.6	8.5	1.8	0.4	0	0	0	T.	0.3	3.5	5.0	31.8
Pine River Dam	14	9.1	8.4	9.5	2.8	2.8	0	0	0	0.1	0.6	5.9	6.8	44.0
Osceola, Wis	11	9.1	8.4	11.7	2.8	T.	0	0	0	T.	0.1	5.5	6.8	44.4
Grantsburg, Wis.	11	9.2	9.0	12.2	4.2	0.1	0	0	0	0	0.1	8.5	8.9	52.2
Upper Minnesota River Valley Group—														
New Ulm	14	8.9	7.5	9.5	1.7	0.2	0	0	0	T.	0.3	3.5	4.4	36.0
Bird Island	14	4.7	5.8	6.0	1.5	0.4	0	0	0	T.	0.5	3.5	3.4	25.8
Milan	14	7.5	8.1	11.2	1.6	0.5	0	0	0	T.	0.6	4.1	6.1	39.7
Minnesota River Watershed Group—														
New London	14	4.6	4.2	7.0	1.7	0.1	0	0	0	0	0.3	2.7	3.4	24.0
Long Prairie	14	5.7	5.5	7.4	2.4	0.4	0	0	0	T.	0.2	3.3	4.4	29.3
Morris	14	5.2	5.4	7.8	2.1	0.5	0	0	0	0	0.6	3.2	4.4	29.2
Fergus Falls	13	6.2	5.7	7.6	2.8	0.4	0	0	0	T.	1.0	5.7	5.8	35.2
Southwestern Group—														
Fairmont	13	5.0	10.0	8.8	1.9	0.1	0	0	0	T.	0.2	3.9	5.3	35.2
Worthington	13	4.1	7.2	7.6	1.2	T.	0	0	0	0	0.3	2.7	3.6	26.7
Lynd	14	6.3	5.1	7.4	2.8	0.5	0	0	0	T.	1.2	2.8	5.3	31.4
Gary, S. D.	11	4.4	6.6	12.4	4.5	0.2	0	0	0	T.	1.2	4.2	4.1	37.6

83 per cent at 7 a.m. and 72 per cent at 7 p.m. Table IX gives the monthly and annual data.

Number of rainy days.—In Table X the number of rainy days during each month and the year is given for thirty-three stations well distributed over the state. The smallest number is 64 at Lynd, Lyon County, and the largest 132 days at Duluth.

Sunshine.—The sunshine is abundant, averaging from 43 to 53 per
: highest amount possible. The daylight hours are materially
ıg the crop-growing season in the northern portion of the
'he southern. The greatest percentage of sunshine is in
n portion and the least in the northeastern part.

Table VII. Prevailing Wind Direction

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Year
Lake of the Woods Group—														
Tower	9	nw.	w.	nw.	w.	w.	w.	w.	w.	w.	w.	w.	nw.	w.
Red River Valley Group—														
St. Vincent-Pembina	23	nw.	nw.	nw.	nw.	nw.	se.	s.	se.	nw.	nw.	nw.	nw.	nw.
Crookston	14	s.	nw.	s.	n.	nw.	s.	sw.	se.	nw.	s.	s.	nw.	s.
Moorhead	28	nw.	nw.	nw.	n.	n.	se.	s.	se.	se.	se.	nw.	nw.	n.
Upper Mississippi River Valley Group—														
Park Rapids	16	nw.	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lake Winnibigoshish	16	nw.	nw.	w.	nw.	nw.	w.	w.	w.	w.	nw.	nw.	nw.	nw.
Sandy Lake Dam	14	nw.	nw.	nw.	se.	e.	e.	nw.	nw.	s.	nw.	nw.	nw.	nw.
Lake Superior Group—														
Mt. Iron	14	nw.	n.	n.	n.	n.	s.	s.	n.	s.	s.	nw.	nw.	n.
Duluth	38	sw.	nw.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	sw.	sw.	ne.
Lower Mississippi River Valley Group—														
La Crosse, Wis.	36	s.	s.	n.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Grand Meadow	15	nw.	nw.	nw.	nw.	nw.	se.	s.	s.	s.	sw.	nw.	nw.	nw.
St. Charles	13	nw.	nw.	se.	se.	nw.	se.	se.	nw.	s.	se.	nw.	nw.	nw.
Red Wing	12	nw.	nw.	nw.	se.	e.	se.	sw.	w.	e.	w.	nw.	nw.	nw.
St. Paul	38	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Lower Minnesota River Valley Group—														
Shakopee	14	nw.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
St. Peter	13	nw.	nw.	nw.	nw.	nw.	nw.	se.	nw.	s.	nw.	nw.	nw.	nw.
Winnebago	9	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	nw.
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	nw.	nw.	nw.	nw.	ne.	s.	s.	s.	s.	s.	nw.	nw.	nw.
Collegeville	14	nw.	nw.	nw.	s.	nw.	sw.	s.	nw.	s.	nw.	nw.	nw.	nw.
Pine River Dam	16	nw.	nw.	nw.	nw.	nw.	w.	w.	nw.	nw.	nw.	nw.	nw.	nw.
Osceola, Wis.	11	s.	s.	n.	n.	s.	s.	s.	s.	s.	n.	n.	s.	s.
Grantsburg, Wis.	11	nw.	nw.	sw.	se.	ne.	sw.	sw.	sw.	sw.	nw.	nw.	nw.	nw.
Upper Minnesota River Valley Group—														
New Ulm	14	nw.	nw.	s.	s.	s.	s.	s.	s.	nw.	nw.	nw.	nw.	nw.
Bird Island	16	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Milan	14	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Minnesota River Watershed Group—														
New London	14	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Long Prairie	14	nw.	nw.	nw.	se.	se.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.
Morris	17	nw.	nw.	s.	s.	s.	s.	s.	s.	s.	s.	n.	s.	s.
Fergus Falls	13	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Southwestern Group—														
Fairmont	15	nw.	nw.	nw.	nw.	nw.	s.	s.	nw.	s.	nw.	nw.	nw.	nw.
Worthington	13	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lynd	14	nw.	nw.	nw.	nw.	se.	nw.	sw.	nw.	nw.	sw.	nw.	nw.	nw.
Gary, S. D.	11	nw.	nw.	nw.	sw.	se.	se.	se.	s	ne.	sw.	nw.	nw.	nw.

Table VIII. Average Hourly Wind Velocity in Miles

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	5	14.3	14.2	15.0	15.1	15.2	11.6	11.3	12.0	12,7	13.9	14.1	14.2	13.6
Moorhead	19	10.3	10.5	11.3	12.0	10.7	10.0	8.3	8.4	10.4	10.4	10.1	10.0	10.2
St. Vinc'nt-Pembina	15	7.7	9.4	10.0	10.7	10.0	8.7	7.5	7.5	9.1	9.3	9.5	8.9	9.2
Two Harbors	6	9.0	8.2	9.7	9.4	7.6	7.4	7.3	7.2	8.0	8.3	8.7	8.9	8.3
La Crosse, Wis.	36	7.1	7.5	8.0	8.5	7.5	6.7	6.0	5.8	6.9	7.5	7.5	7.2	7.2
St. Paul	36	7.8	8.3	8.8	9.3	8.7	7.7	7.1	7.1	8.0	8.5	8.1	7.8	8.1
Minneapolis	18	11.5	11.6	12.3	12.8	12.1	10.3	9.9	9.9	11.6	11.7	11.0	11.2	11.3
Faribault	7	9.4	9.1	9.4	11.0	9.0	7.3	5.9	6.4	7.8	8.8	9.0	9.1	8.5
Collegeville	11	9.5	9.6	11.0	12.2	11.1	10.0	9.4	9.4	10.9	9.5	9.9	9.9	10.2

Table IX. Mean Relative Humidity in Degrees

Stations		Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth..........	8 a.m.	21	83	83	81	76	76	79	79	81	82	81	83	84	81
	8 p.m.	21	77	75	71	65	64	69	65	69	71	72	76	78	71
Moorhead	8 a.m.	21	89	88	88	84	79	84	86	87	87	84	89	89	86
	8 p.m.	21	86	86	82	65	56	62	64	61	63	69	81	85	72
St. Vincent.....	8 a.m.	4	80	80	88	88	79	84	88	90	87	89	89	87	86
	8 p.m.	4	83	86	88	77	58	66	71	70	71	78	89	89	77
La Crosse, Wis..	8 a.m.	21	83	82	79	74	75	79	81	85	85	81	81	83	81
St. Paul.......	8 a.m.	21	84	84	81	75	75	79	79	83	83	81	81	83	81
	8 p.m.	21	76	75	68	55	54	58	55	56	60	63	69	76	64
Minneapolis......	8 p.m.	7	83	79	76	66	66	67	65	68	72	73	79	83	74

Table X. Number of Days with 0.01 Inch or More of Precipitation

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Lake of the Woods Group—														
Tower	9	5	4	6	5	8	9	10	8	10	7	5	5	82
Red River Valley Group—														
St. Vincent-Pembina...	25	7	6	7	7	8	11	10	9	8	7	7	7	94
Crookston	14	4	4	5	6	8	10	8	8	6	5	3	4	71
Moorhead	28	8	9	8	9	11	12	10	9	8	8	7	8	107
Upper Mississippi River Valley Group—														
Park Rapids..........	14	8	7	10	9	11	13	11	10	9	9	7	8	112
Lake Winnibigoshish...	15	6	4	7	6	10	10	9	8	7	5	5	6	83
Sandy Lake Dam.....	14	6	6	8	6	10	10	10	10	9	8	6	6	95
Lake Superior Group—														
Mt. Iron.............	14	5	4	5	5	9	11	10	9	9	7	5	6	85
Duluth	38	10	9	10	9	12	14	12	12	12	10	11	11	132
Lower Mississippi River Valley Group—														
La Crosse, Wis........	36	10	8	10	10	12	12	10	9	10	9	8	10	120
Grand Meadow........	15	6	5	7	7	12	9	9	8	8	7	6	6	90
St. Charles...........	12	5	4	6	6	9	11	7	6	8	7	5	4	78
Red Wing.............	10	5	5	6	7	11	10	7	7	8	6	5	5	82
St. Paul.............	38	9	8	10	10	12	12	10	10	9	9	8	9	114
Lower Minnesota River Valley Group—														
Shakopee	14	5	5	7	8	11	10	9	9	9	8	6	5	92
St. Peter.............	12	3	3	5	6	10	9	7	7	6	5	3	2	66
Winnebago	10	4	4	6	6	12	11	9	9	7	7	3	4	82
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8	7	9	9	12	12	9	9	8	9	7	8	107
Collegeville	14	6	5	8	7	10	12	10	10	9	8	6	5	96
Pine River Dam.......	15	4	4	6	6	9	10	8	8	7	6	4	4	76
Osceola, Wis..........	11	7	5	6	6	8	9	8	7	6	7	5	5	79
Grantsburg, Wis.......	11	5	4	5	6	8	7	7	6	5	4	5	6	68
Upper Minnesota River Valley Group—														
New Ulm.............	14	5	5	7	7	11	11	8	8	8	7	5	4	86
Bird Island...........	14	4	3	6	7	10	10	8	8	8	6	5	3	78
Milan	14	6	5	7	7	9	11	8	8	7	6	5	5	84
M[illegible]esota River Water-[illegible]d Group—														
[illegible]London.........	14	3	3	5	5	9	9	7	6	6	5	4	3	65
[illegible]airie..........	14	4	4	6	8	10	11	8	8	8	7	5	3	82
[illegible]...........	16	4	4	6	7	11	12	9	9	7	6	4	4	83
[illegible]...........	13	11	8	11	9	12	15	11	11	10	8	7	10	123
[illegible] Group—														
[illegible]........	15	4	4	5	6	10	8	7	7	7	5	3	3	69
[illegible]......	13	4	4	4	6	11	10	14	8	6	5	4	4	80
[illegible]....	14	3	3	5	5	8	9	7	8	6	4	3	3	64
[illegible]..	11	3	2	3	5	6	5	6	5	4	4	3	1	47

The precipitation in the area embraced in the present report, as shown Figure 12, increases from northwest to southeast, being about 25 :hes in the northwest part and over 32 inches in the southeast. Although re is an increase on approaching Lake Superior the influence of the in increasing precipitation near its shore seems to be very slight, r in parts of Minnesota farther south where there is no lake influence imilar increase in the amount of precipitation is found in passing from rthwest to southeast.

CHAPTER III

AGRICULTURAL CONDITIONS AND LAND CLASSIFICATION IN THE NORTHEAST QUARTER OF MINNESOTA

GENERAL STATEMENT

The northeast quarter of Minnesota lies within the area of mixed coniferous and deciduous forests (Figure 3), and was heavily wooded, except in some of the muskeg swamps, and in narrow marshy strips bordering lakes and streams. The sandy and loose-textured soils are occupied largely by pine forests, while the clayey or heavier classes of soil carry usually a mixed growth, embracing deciduous as well as coniferous trees.

Agricultural development is as yet very limited in all parts of this area. In most localities farming has begun within the past ten or fifteen years. The clearing of stumps, draining of swamps, and opening of roads, each require much labor and thus retard a rapid agricultural development. The region is, however, sufficiently well watered, and large areas of it have a soil productive enough to give adequate returns for the expenditure of labor required to bring the land under cultivation. This region is not affected by drouths in late summer such as often cut short the pasturage in districts farther south and west. Very little feeding is, therefore, required until the pastures become snow-covered.

Railway facilities are good in Carlton and much of Aitkin County and over the territory lying between the Mesabi Iron Range and Lake Superior. Koochiching County also has fair railway advantages. There is urgent need for a railway leading northeastward from Duluth through Lake and Cook counties. At present the Minnesota and Northeastern, used largely for lumbering operations, furnishes an outlet for southern Lake County. Boat service is maintained along the shore of Lake Superior from May 1 to November 30, thus furnishing an outlet for the produce of Cook as well as Lake County.

The larger part of the population of this northeast quarter of Minnesota is along the shore of Lake Superior and the mining towns on the iron ranges and in villages scattered along the railways. Not more than twenty per cent of the population are engaged in agricultural pursuits. Of this population a considerable part combine other pursuits with farming and are employed part of their time in the cities or in logging camps. Year by year, however, a larger percentage of the farmers are giving their entire time to farm development.

The three counties north of Lake Superior each have large areas with rock hills which carry only a scanty cover of drift. The scanty soil combined with the steepness of slope renders them of little or no agricultural value. These rocky lands are largely embraced in the National Forest and yield better returns from their forests than could be obtained by farming them. These three counties have, however, certain advantages because of their frontage on Lake Superior. A narrow strip along the lake shore should become a profitable one for the growing of vegetables and even of hardy fruits, which can be readily marketed by boats running to Duluth. The loose-textured soil of this belt also adapts it for the growth of garden truck.

Swamps are numerous in every county in the northeast quarter of the state, and there are extensive muskegs in western St. Louis, Koochiching, and Aitkin counties. The drainage surveys have shown, however, that in the largest swamps as well as in the smaller ones the surface slope is generally sufficient to insure effective drainage. The soil of the swamps also is generally of such a nature as to be very productive when drained. The water courses which have developed in and near these swamps by natural drainage have in most cases channels of sufficient capacity to carry off all water which would be discharged into them from the ditches necessary to drain the swamp areas. A considerable improvement in the drainage and reduction of the area of swamp lands may easily be effected by removing obstructions from the natural water courses, such as old beaver dams and the fallen timber and other obstructing material. Such obstructions are found in nearly all of the small stream channels throughout the area. Large areas of these swamp lands are held by the State, and many projects for their reclamation have been worked out by the State Drainage Engineer and embodied in his report for 1906.

There are wide differences in the character of the glacial deposits in northeastern Minnesota. The cause of some of these differences was the peculiar relations of the deposits to the melting ice, and some were caused by differences in the rock material contained in the drift. Drift laid down under the ice naturally contains a considerable amount of fine clayey or loamy material along with the coarser rock constituents. But drift laid down at the edge of the ice has in places had the fine material largely removed by the waters discharging from the ice border, and the coarse material is thus concentrated into beds of gravel and cobble. There are places, however, where lakes were held between the ice and the higher country outside, or in regions where the escape of the water was inadequate. In such places a fine se[illegible]nt was laid down outside the ice on the beds of the lakes or ponds[illegible]

A. GARDEN PLOT OF ANTHONY GASCO ON LAKE HARRIET, LAKE COUNTY
PHOTO BY A. H. ELFTMAN

B. FARM ON SHORE OF LAKE SUPERIOR AT LUTZEN, COOK COUNTY
TERRACING MARKS HIGHER LAKE LEVELS

The temporary Lake Aitkin, which occupied the district traversed by the Mississippi in its course through Aitkin County, deposited a fine and highly productive sediment over much of its bed. The flat land in the St. Louis basin, covered by Lake Upham, now carries deposits of fine sand and silt over a wide area in western St. Louis and northeastern Aitkin County. It embraces the extensive muskeg swamps of that region.

On the bed of Lake Duluth, at its southwest end, in Carlton County and neighboring parts of Wisconsin, there is considerable clay, but in a narrow strip exposed on the north side of Lake Superior there has been in places a removal of the fine material and a concentration of coarse material in the bars and beaches of the lake.

Lake Agassiz extended from the Red River basin and plains of Manitoba as far east as the northwest part of the area herein described (Plate I). All of Koochiching County except a strip two to eight miles wide on its southern border was covered by this lake. It also covered about twenty townships in the northwest part of St. Louis County. The part in Koochiching County has a nearly plane surface and a considerable deposit of fine lake sediment except on the immediate borders of Rainy Lake and small areas in the southeast part of the county where rock knobs are exposed. The lake deposits with heavy soil extend up Little Fork valley into St. Louis County and are found in narrow lowland strips among the rock hills in northwestern St. Louis County. The greater part of this lake area inside the limits of St. Louis County, however, has a rocky surface much of which was swept bare by the action of the lake waves, and thus rendered of little value for agriculture.

The kind of rock material contained in the drift depends to some extent upon the direction from which the ice invaded this region. As already indicated the studies of the deposits have brought out the interesting fact that the ice invasions came from three directions, the northwest, the north, and the east. The invasion from the northwest was by ice which covered much of Manitoba and spread over a great part of northern Minnesota. It brought in deposits of drift containing large amounts of limestone which the ice had gathered in its passage across limestone formations in Manitoba. This is known as the Keewatin drift, since the ice started from the region formerly called the Keewatin district of central Canada (but now largely included in Manitoba). It is also known as the gray drift, this term having been applied by Winchell and his associates in their reports in the Minnesota Geological Survey. The color is gray, however, only in the unoxidized portions, and the surface of the drift, that has been oxidized, has a brown color. There are also places in the vicinity of the Mesabi Iron Range, where on account of the introduction of reddish material from the iron formations, it all

presents a red color. The color name, therefore, becomes rather confusing when one attempts to apply it widely. For this reason the term Keewatin drift is used in the present report.

The border of the Keewatin drift is indicated on Plate I and also on Figure 2. On the northeast it lies only a few miles south of the Canadian line from the mouth of Rainy Lake eastward to Nameokan Lake in St. Louis County. It then leads southward to the west end of Vermilion Lake. Then after a slight eastward turn in the Little Fork drainage basin it swings southward and comes to the Mesabi Iron Range near Chisholm. But the high part of the range from there westward about to the Itasca County line seems to have stood above its limits. On passing over the range into the basin south of it the Keewatin ice spread out widely over the St. Louis drainage basin and also down the Mississippi to the edge of Crow Wing County. The southwest limits run through northwestern Aitkin County and thence westward across Cass County to the south of Leech Lake, passing beyond the limits of the area under discussion. In the district covered by the Keewatin drift the glacial deposits are exceptionally rich and of a less stony character than in districts to the east and south which were covered by drifts derived from other sources.

Ice invaded the northeast part of Minnesota also partly by a westward movement of the Labrador ice sheet through the Superior basin and partly by a southward movement from the district of Patricia in the neighboring part of Canada. A part of the drift deposited by these invasions is called the Superior drift and the other part the Patrician drift. Both of these drifts have a reddish color owing to the large amount of red rock material incorporated in them, and they embrace what is termed the red drift of Minnesota in the reports of the Winchell Survey.

The relations of the Patrician ice movement to the Superior and Keewatin ice movements are somewhat complex. The Patrician movement extended over eastern Minnesota southward a little beyond St. Paul into Scott and Dakota counties, and covered at least one third of the state. It is found to have done so before the movements from the Keewatin and Superior ice fields had reached into northeastern Minnesota, for territory which it occupied was later invaded to some extent by each of these ice fields, and the deposits of the Patrician ice are overlain by the Keewatin and Superior drifts in such regions of overlap. The borders of the drift of the Superior and of the Keewatin ice approach each other closely for a few miles in southwestern St. Louis and northwestern Carlton and the eastern edge of Aitkin County, and the Patrician drift is there found beneath one or the other of them. (See Plate II A and II B). Farther south in Aitkin and neighboring counties, as shown in

A. SHORES AND ISLANDS OF VERMILION LAKE

B. CROSS RIVER MEANDERING THROUGH A SPRUCE SWAMP IN ITS HEADWATERS

Figure 2, the Patrician drift is at the surface. It is also at the surface at the northeast in St. Louis, Lake, and Cook counties between the drift of the Keewatin ice field and that of the Superior lobe of the Labrador ice field. The precise relations of the Superior lobe and Patrician ice in the district north of Lake Superior will be taken up in the discussion of Lake County. Attention is accordingly directed here only to the differences in the character of their drifts.

In the drift brought in by the Superior lobe there is on the whole a large proportion of loamy material in which the coarse crystalline rocks are imbedded. The soil is what might appropriately be termed stony loam. It becomes more gravelly on its northwest edge in the headwaters of Cloquet River because of the discharge of water there along the ice border. The drift deposited by the Patrician ice is generally very stony because of the derivation of its material from the crystalline rock formations over which the ice passed, and which do not readily break down into clayey material. The contrast between it and the drift of the Superior lobe is, however, less striking than between it and the drift of the Keewatin ice sheet, and there are places where the drift of the Superior lobe is fully as stony as that from the Patrician ice. The larger amount of loam in the Superior drift is due in part to the ponded conditions of water along the northwest edge of the Superior ice lobe, there having been ready escape for water along only a part of the border in the headwaters of Cloquet River. It is thought, however, that the formations over which the Superior lobe passed, such as the diabase of Beaver Bay and certain gabbro rocks contributed more material that is easily reduced to clay than did those formations found in the area over which the Patrician ice sheet passed. It was in connection with the retreat of the Superior ice and the Keewatin ice that the glacial lakes, Duluth and Agassiz, noted above were formed.

DESCRIPTIONS OF COUNTIES

In the descriptions of counties which follow the county taken first is in the northeast corner of Minnesota, and after that counties to the west and south to the southern border of the area are discussed. A few data from the census of 1910 are presented in addition to the results of the land classification on a geologic basis.

COOK COUNTY

The recent studies in Cook County were mainly in the part near the shore of Lake Superior where farming has been begun and roads opened. Data concerning the less accessible areas have been obtained from the geological reports of the earlier Geological Survey and from Dr. Arthur

H. Elftman, a member of that survey, who also in 1913 assisted in part of the work in Lake and Cook counties.

Bare rock or rock with a very scanty drift covering occupies about one third of the area of the county, mainly in the north part, and mainly within the limits of the National Forest. But there is also a strip of rugged land known as the "Sawtooth Mountains" which lies near the Superior shore westward from Grand Marais. Several townships in the eastern end of the county are also rugged and thinly covered with drift.

The lakes of Cook County, including those along the Canadian border, are estimated by Mr. George A. Ralph,[1] to cover 274 square miles, while the swamps embrace 135 square miles. Their combined area, 409 square miles, is over one fourth of the county. This, together with the rough and rocky areas, amounts to nearly 60 per cent of the county. Of the remaining 40 per cent a considerable part can not be brought under cultivation except at great expense in clearing of stones and stumps. It may, therefore, prove to be more profitable in forest than under cultivation.

The tracts of heavy drift embrace some moraines, the position and extent of which may be seen by reference to Plate I. Parts of these moraines have a very rough surface with sharp knolls inclosing small swamps. More commonly the glacial deposits are gently undulating with slopes easy to cultivate. The part along the shore which was covered by the waters of Lake Duluth and lower lake stages down to the present Lake Superior, includes numerous gravelly ridges or beaches formed at different levels corresponding to the successive lake levels. The slopes between these gravel ridges have wave-washed drift consisting largely of coarse material. Very little fine sediment was deposited by the lake on this part of the shore. The soil, however, has proved to be productive in the growth of vegetables and cereals.

The prevailing type of soil in the tracts of heavy drift is a stony loam. This is true of moraines, till plains, and of the part within the limits of Lake Duluth. Dr. Elftman reported that there is a strip of heavy drift embraced in flat areas among rock hills on the south side of Pigeon River in Ranges 3, 4, 5, and 6 E. in which a clayey drift is found, which, when cleared and drained, is likely to become valuable agricultural district. It lies partly within the limits of Lake Duluth, but at the west the deposits are somewhat higher than the level of that lake. They may, however, have been laid down in ponded waters along the ice border.

Agricultural development is at present mainly in a narrow strip scarcely five miles wide along the shore of Lake Superior. There is a belt about ten miles wide lying north of the "Sawtooth Mountains" from

[1] G. A. Ralph. *Engineer's Report on Topographical and Drainage Survey*, Minnesota, 1906.

A. FIELD OF OATS ON KEEWATIN TILL PLAIN IN ST. LOUIS COUNTY

B. DAIRY FARM, ST. LOUIS COUNTY

Cascade River westward to Temperance River and northward to Brule Lake, in which the drift cover is heavier than to the north. Parts of this may be suitable for agriculture. The roughness of surface, stony character of the drift, and the likelihood of frost in this depression back of the Sawtooth range give the area of thicker drift but little advantage over the rocky area to the north for crop raising, but it should give good returns in forest. The flat areas of heavy drift along Pigeon River, noted above, are also as yet undeveloped, and are likely to remain so until a railway line is constructed which will give an outlet for the produce.

From the census of 1910 it appears that the number of farms had increased in the preceding decade from 36 to 146. Of these, 115 have an area of between 100 and 175 acres, and two have an area over 500 acres. On many there has been very little cultivation of the soil, the average acres of improved land per farm in 1910 being only 10.7. Thus far the market facilities are restricted mainly to the season of boat traffic on Lake Superior which runs from May 1 to November 30. The Minnesota and Northeastern Railroad, however, has now extended its line to the southwest part of the county and thus opened winter connections with Duluth. Vegetables are as yet grown more extensively than cereals but the census returns show that oats, wheat, barley, and rye, have each a good yield per acre.

LAKE COUNTY

In Lake County a strip several miles wide along the shore of Lake Superior in which the principal settlement occurs was examined in detail. Lines of traverse were also carried into the unsettled parts of the county, lumber camps being used as a base from which to work. Dr. Arthur H. Elftman, who joined in part of this investigation, also greatly aided by supplying information concerning the character of soils in several townships in the northern half of the county which he had examined geologically some years previous under the direction of Professor N. H. Winchell. Information concerning the character of land inside the limits of the National Forest was obtained also from the foresters located there.

The northern part of the county, as far south as Tp. 61, is a very broken district with rock knobs among which are lakes and swamps. It carries only a thin coating of glacial drift on the hills, and there is very little easily tillable land. The greater part of this rocky area is included in the National Forest. There are other bare rock ridges in the southern part of Lake County within the limits of the glacial Lake Duluth which owe their bareness in part to the work of the lake waves in removing the drift covering. These rock outcrops are numerous in the southern part of the county for several miles back from the present shore

and up to an altitude of 800 to 1,000 feet above the level of Lake Superior. There are several townships lying between these rock ranges and those of the northern half of the county in which the drift is so heavy as to nearly conceal even high rock hills and ridges. There are also flat areas among the exposed rock ranges near the shore of Lake Superior in which heavy deposits of drift occur.

The greater part of Lake County was covered by Patrician ice which came in from the north, there being only a strip fifteen to twenty miles wide next to Lake Superior which was covered by the Superior ice field. Each of these ice fields produced a great system of moraines which become interlocked in the eastern part of Lake County. The system formed by the Patrician ice field leads westward from Tps. 59 and 60 R. 7 W. across this county into St. Louis County, covering much of Tp. 59 R. 8W. and Tp. 60 Rs. 9, 10, and 11W. The several headwater branches of Isabella River start in this morainic system and Stony River has most of its course among its ridges. Between the constituent morainic ridges there are narrow strips of gravel plain formed as outwash from the ice border in the course of the development of the morainic system. The amount of drift in this morainic system is several times as great, square mile for square mile, as in the district to the north of it, in the northern half of Lake County.

A morainic system of the Superior lobe, which joins as a correlative of that of the Patrician ice field just described, leads from their place of junction, which is in Tp. 59, Rs. 7 and 8W, southwestward parallel to the shore of Lake Superior through Lake County into St. Louis County. Its inner border is twelve to fourteen miles from the Lake while the outer border is usually sixteen to eighteen miles. Its position may be seen by reference to Plate I. The highest land areas in Lake County are at the junction of the morainic systems, there being a few knolls on the moraines, which by barometric measurement, exceed 2,000 feet above the sea. Each of the morainic systems descends in passing westward from there to the St. Louis County line to an altitude of about 1,700 feet along their crests. The inner border of the Superior lobe, which is considerably lower than the crest, is, however, generally above 1,500 feet.

In topography the great morainic systems are rough and approach in that respect the rock areas of the northern part of the county, there being numerous hills 50 to 100 feet high with steep sides difficult of cultivation. For this reason settlements in Lake County have thus far avoided these morainic systems.

There are several townships lying between these two great morainic systems in western Lake County which are covered by drift belonging to the Patrician ice movement, the ice having melted there prior to the de-

A. BREAKING GROUND AT MEADOWLANDS

B. STOCK FARM AT MEADOWLANDS

C. FARM PREMISES AT MEADOWLANDS

velopment of the morainic systems. Scattered drift knolls and ridges are found in these townships but they do not appear to form definite morainic belts. The greater part of the surface is nearly plane and much of it is swampy. This district was traversed by lines of glacial drainage which ran away from the great morainic systems toward the southwest. The headwaters of Cloquet and St. Louis rivers are in channels which were developed along those lines by the escape of the glacial waters. The swamps are largely underlaid by sand and gravel deposits brought in by the glacial drainage.

On the slope toward Lake Superior there are narrow strips of moraine developed as the ice border halted in its retreat into the Superior basin. They are far less conspicuous, however, than the great morainic systems above noted.

From the junction of the two great morainic systems in T. 59, R. 7W. northeastward into Cook County where the two ice fields were coalesced they did not form moraines. Instead, the ice fields appear to have blocked each other's movements almost completely and to have become ramified near their junction by tunnels through which the water formed by the melting of the ice flowed and deposited gravel and sand in the tunnels. After the ice was all melted these deposits of gravel and sand settled down on the underlying drift-covered surface, and remained there as steep sided gravel ridges called eskers. In Plate IV A one of these ridges which is 90 feet high is shown and it will be noted that the crest is barely wide enough for a wagon track. Eskers are found quite commonly in the glaciated districts. In this locality they are found at the junction of two ice fields but such eskers occur frequently inside the area of a single ice field. They formed when ice movement had practically ceased and where the ice had become ramified by tunnels. Eskers furnish good material for road building rather than good soil. They are of great value for road material, especially in districts where there is a clayey drift.

The waters of Lake Duluth are found to have extended back to a distance of four or five miles from the present shore of Lake Superior in the region from Knife River as far northeast as Beaver Bay, though for several miles southwest from Beaver Bay a rock ridge lying back only about two miles from the shore rose slightly above the lake level. From Beaver Bay northeastward the waters of Lake Duluth extended only one and a half to two miles back from the present lake except in narrow inlets in the valleys of Baptism and Manitou rivers. Rocky ridges bordering Lake Superior have greater breadth from Beaver Bay northeastward than they have to the southwest. The beaches of Lake Duluth are ill-defined in these rocky areas but are distinctly seen in the form of

definite gravel ridges where the shore was of glacial deposits. These ridges occur at various levels marking the successive lake stages down to the present shore. The highest shore is not far from 550 feet above Lake Superior. It shows a slight rise from southwest to northeast in its course through the county.

The rough areas of rock ridges and hills are estimated to occupy about 40 per cent of the area of Lake County. The lakes occupy about 12 per cent and the swamps, as estimated by the State Drainage Engineer, embrace 297 square miles or 14 per cent of the county. There thus remains only about one third of the area of the county occupied by the better classes of land. Of this a large part is stony loam with numerous cobblestones as well as bowlders in the soil and on the surface. A narrow strip with heavy clay soil and relatively few stones is found along and near the shore of Lake Superior in the southwest part of the county below the level of the highest beach of Lake Duluth. A looser-textured clay loam with only a moderate number of stones included is found above the level of Lake Duluth in Tp. 54, R. 10W., Tp. 55, Rs. 9 and 10W., and Tp. 56, R. 9W. This district is traversed by the Minnesota and Northeastern Railroad, which thus gives it an outlet for the marketing of products. Both of the great morainic systems are very stony but the one formed by the Superior lobe appears to contain somewhat more loam in the soil than that formed by the Patrician ice field. The district lying between these moraines in the western part of Lake County is also very thickly strewn with stony material, except along lines of glacial drainage, where some deposits of gravel and sand occur.

Nearly all the farming settlements in Lake County are in the two areas of clay and clay loam above noted which lie near the Lake Superior shore, and principally within ten miles of it. There are, however, two settlements more remote. One in the western part of the county in the vicinity of Toimi Post Office has a few settlers. The main settlement of about 75 families is in the adjacent part of St. Louis County. Another in Tp. 59, R. 8W. just west of the junction of the two great morainic systems above noted has about 40 settlers. This settlement has the distinction of being the most elevated one in the state, the altitude being between 1,800 and 2,000 feet. Notwithstanding the high altitude, and remoteness from the lake, cereals and vegetables have been grown with marked success. The soil is a stony loam with considerable sandy admixture both in this settlement and the one around Toimi. There are also a few settlers northeast of Ely in Tp. 63, R. 11W., and a few in Tp. 62, R. 10W.

A single farm has been opened on the east shore of Harriet Lake in Tp. 60, R. 6W. by Anthony Gasco, a view of whose premises is given

A. FERTILE VALLEY NORTH OF VERMILION LAKE AT "HALF-WAY HOUSE"

B. FARM ON THE STONY PATRICIAN DRIFT AT TOWER

in Plate V A. This farm is at an altitude of nearly 1,800 feet or but slightly lower than that of the settlement in Tp. 59, R. 8W. When visited, on September 15, 1913, there had been no killing frost. Sweet corn, pumpkins, cucumbers, lettuce, turnips, cabbage, beets, tomatoes, and potatoes were all in flourishing condition, as well as cultivated flowers of many kinds. In the year 1912 Mr. Gasco raised $300 worth of garden truck on less than five acres.

The census of 1910 reports only 1.7 per cent of the county, or 34.8 square miles, to be in farms, and only 10.7 per cent of the farm lands to be improved. The crops grown in 1909 were valued at $47,187. Of this $15,659 were for vegetables, and $18,742 for hay and forage. The cereal crop is rated at only $323, there being but 15 acres reported. There has been considerable advance in the development of farms since the census of 1910 was taken, yet it is still true that only a small part of the land that is suitable for cultivation in Lake County has been developed.

ST. LOUIS COUNTY

St. Louis County of which Duluth is the county seat, embraces more than one third of the northeast quarter of Minnesota, its area, according to the Census of 1910, being 6,503 square miles. It extends from the west end of Lake Superior northward to Rainy Lake on the Canadian border, or from T. 48N. to T. 71N., a distance of fully 130 miles. Its north and south ends are irregular, but for 88 miles, from T. 52 to T. 66 inclusive, the county has a regular width of 60 miles. It is traversed by several railway lines radiating from Duluth. Only one of these, the Duluth, Winnipeg and Pacific, extends through to Canada. Several lines have termini in the Mesabi Iron Range.

Nearly all the county is a tableland standing 600 to 900 feet above Lake Superior, or 1,200 to 1,500 feet above sea level. The Mesabi Iron Range and the associated rock ridges rise in places to 1,800 feet above the sea. A prominent moraine in the southeast part of the county is about 1,700 feet where it enters from Lake County, and the bed-rock surface there attains an altitude of about 1,600 feet. The rock surface has an altitude of 1,500 to 1,700 feet along much of the eastern part of the county. The altitude decreases westward in the district on each side of the Mesabi range. That range reaches its highest elevation of about 1,800 feet in the central part of the county.

For a distance of 30 to 35 miles south from the Canadian boundary, or as far south as Pelican, Vermilion, and Birch lakes, the drift is very scanty on the hills and ridges. The Mesabi Range is very thinly coated with drift in places, though its south slope and the portion west from Chisholm carry a relatively heavy coating. Between the Mesabi Range

and Vermilion Lake, in the drainage areas of Sturgeon and Little Fork rivers, there is generally a heavy cover of drift. The drift cover is heavy also south of the Mesabi Range, except in a narrow strip fronting on Lake Superior where bare ledges are conspicuous. These ledges are chiefly in T. 49, R. 15W., T. 50, R. 14W., and T. 51, R. 13W. The drift of this county was brought in from the three ice fields discussed in the introductory statement. The Superior ice lobe covered the county from the direction of Lake Superior as far northwest as the valley of Cloquet River. The Keewatin ice field extended into the county from the northwest covering about twenty townships north of the Mesabi Iron Range, and a still larger area in the St. Louis basin south of the range. It did not, however, override the portion of the Mesabi Range in this county, but came across the range in Itasca County, and then spread eastward along the south side of the range, in St. Louis County.

The ice from the Patrician district covered the northeastern part of the county as late as the time when the other two ice fields were occupying the southern and western portions, as just described. The morainic system of the Patrician ice sheet, which is correlated with the great morainic system of the Superior lobe, as indicated in the discussion of Lake County, continues into St. Louis County to Vermilion Lake. From that lake northward the Patrician and Keewatin ice fields may have been nearly confluent along a line lying not far from the Vermilion River. Extensive areas of Patrician drift in eastern St. Louis County and along the Mesabi Range are a little older than these great morainic systems, and, as already stated, the Patrician drift of southwestern St. Louis County and neighboring districts was encroached upon by the Superior and Keewatin ice fields and to that extent its drift deposit lies buried beneath their drifts. (See Plate II A and II B.)

The lakes of St. Louis County are estimated to occupy 365 square miles, not including those along the Canadian border. The great majority are less than one square mile in area, but there are a few of considerable size within the limits of this county. The area of Vermilion Lake is about 70 square miles, of Lake Kapetogama fully 30 square miles, of Pelican Lake 20 square miles, and of Trout Lake 11 square miles.

The swamp lands of St. Louis County, as estimated by the State Drainage Engineer in his report for 1906, occupy 1,862 square miles, of which 372 are open swamp with little or no forest growth. Much that is now classed, and which appears in the Land Survey plats as swamp land, will drain naturally when cleared of brush with but little aid by ditching. It is estimated that the rock hills and ranges of St. Louis County embrace an area of nearly 1,700 square miles, or somewhat more

A. FARM ON CLAYEY KEEWATIN DRIFT EAST OF COOK

B. PIONEER MARKETING AT COOK

than one fourth of the county. The area of dry land with thick drift cover is, however, still larger than the rock areas, being estimated at 2,600 square miles, or about 40 per cent of the county.

The area covered by Lake Duluth in this county is only about 100 square miles, the highest shore line being in places scarcely a mile back from the lake. In the eastern part of the county, however, the distance increases to fully five miles.

The most extensive class of soil in St. Louis County is the stony loam. This is the dominant type in the great morainic system of the Superior lobe which runs southwestward across the southern part of the county, though included among those morainic ridges there are nearly level areas in which a somewhat heavy clay with comparatively few stones occurs. (See Plates XII A, XII B.) The Patrician drift in the eastern part of the county is as a rule exceedingly stony both in the ridges and on the level areas. On the Mesabi Range the drift is in places so thickly set with bowlders as to form a literal pavement. (See Plate XV A). In the district between the Mesabi range and Vermilion Lake there are rough and stony morainic strips (see Plate IX B) between which are nearly plane areas part of which are of sand and gravel and part of stony drift similar to that in the moraines.

In the St. Louis basin, south of the Mesabi Iron Range, there are several classes of soil. A strip several miles wide immediately south of the iron range has a clayey till with relatively few stones imbedded in it, which was deposited by the Keewatin ice sheet. (See Plate II B.) This kind of drift is also present on the south side of St. Louis River in several townships lying east of the Duluth, Winnipeg and Pacific Railroad, and north of White Face River.

Another extensive deposit in the St. Louis basin is a fine sand which borders the river for most of its course from the crossing of the Duluth and Iron Range Railroad down to the crossing of the Coleraine branch of the Duluth, Mesabi and Northern Railroad, and which also spreads westward to within a few miles of the Mesabi range in the drainage basin of Swan River. This sand apparently underlies a considerable part of the muskeg in the western part of St. Louis County.

From the crossing of the Coleraine branch of the Duluth, Mesabi and Northern down the St. Louis and Whiteface valleys there is a deposit composed more of silt than of sand which seems to have been laid down in Lake Upham, the lake which once occupied this area and discharged through the St. Louis River below Floodwood. The same deposit is exposed along the Floodwood River for many miles above its mouth, and is found to underlie the muskeg swamps for some distance north and west of Floodwood. The Meadowlands Experimental Farm in T. 53, R. 19W. lies within the limits of this silt deposit, (see Plates VIII A,

VIII B, and VIII C), and a farming district in the vicinity of Floodwood is also developed within it.

In the area covered by Lake Duluth fully 80 of its 100 square miles have a clayey drift in which stones are relatively scarce compared with their number outside of the lake area. About 10 square miles are embraced in rock ranges in which the drift has been nearly all washed away by lake action. The remaining 10 square miles are occupied by drift of a stony and sandy character. This kind of drift is found chiefly from Duluth southwestward.

In the western part of the county on the borders of Little Fork River (See Plates X A and XI A) and the lower course of Sturgeon River there is an area of over 200 square miles of clayey deposits in which very few stones occur, and which is already being developed extensively, as the soil is productive and easily cultivated. A considerable part of this area as noted above was swept by a forest fire some fifty years ago. Less extensive clayey tracts, occupying perhaps 40 square miles (See Plate IX A), are found along the borders of Vermilion River from T. 65N. to Crane Lake in T. 67N., R. 17W. These clayey tracts are in the area once covered by the waters of Lake Agassiz and the material forming the soils may be in part a lake deposit. A large part also of the area covered by Lake Agassiz in northwestern St. Louis County is hilly and many of the hills have little drift coating. There are, however, among the hills, deposits of the calcareous clayey till of the Keewatin ice field, which promise to become productive when cleared and brought under cultivation.

The census of 1910 shows 426½ square miles, or 6.6 per cent of the area of the county, to be in farms, and of these 15 per cent is improved land. The amount of improved land has probably more than doubled in the five years since the census was taken. The crops of 1909 were valued at $919,360. Of this about one third was in hay and forage. The value of the vegetables is placed at $220,556, which is about nine times the value of the cereals of that year ($24,449). The yield of potatoes averages about 150 bushels per acre for the 2,378 acres planted to that crop. Within the past five years many residents of Duluth have invested in small tracts of one to five acres on the hills bordering the city and are developing them rapidly in truck gardens.

KOOCHICHING COUNTY

Koochiching County, with International Falls as its county seat, occupies the northwest part of the area under discussion. Rainy Lake and Rainy River form its northern boundary and separate it from Canada. It is traversed from southwest to northeast by the Minneapolis and In-

A. CLEARING IN POPLAR FOREST ON LITTLE FORK RIVER, ST. LOUIS COUNTY

B. DITCHING A MUSKEG IN ST. LOUIS COUNTY

C. JACK PINE OVER 100 FEET HIGH AT STURGEON LAKE, ST. LOUIS COUNTY

ternational Falls Railroad and its northeast corner is crossed by the Duluth, Rainy Lake and Winnipeg Railroad. The Minnesota, Dakota and Western has a passenger line from International Falls to Loman, and a logging road south from Little Fork into Itasca County. The principal inhabitation is along the lines of the railways and along Rainy River. Boat service on Rainy River is maintained from International Falls down to Lake of the Woods throughout the summer season.

The area of the county is 3,141 square miles which was cut off from Itasca County in 1906. Three ranges of townships on its western side, embracing an area of 1,027 square miles, have been described in the report on the northwest quarter of Minnesota, *Bulletin 12,* Minnesota Geological Survey, the 94th meridian being the boundary between the area there described and the portion of the county here discussed.

The greater part of the county falls within the limits of the glacial Lake Agassiz, less than 12 per cent being above the level of the highest shore of that lake. Of the part lying east of the 94th meridian only 170 square miles of the 2,114 are above the level of Lake Agassiz shore lines. The area covered by the lake is nearly half swamp land. The better drained areas are chiefly a calcareous bowlder clay composed of the Keewatin drift. Thin deposits of lake silt have been laid down over the flatter portions. These well-drained areas are largely found on the immediate borders of the streams, although in the eastern part of the county they extend more widely over the interstream areas. In the northeastern part of the county on the borders of Rainy Lake and southward to Lake Kabetogama there are rock hills with very thin deposits of drift on their slopes. South of these rock hills there are ridges of drift which seem to be composed mainly of Patrician drift but which are coated with the calcareous Keewatin drift. They appear, therefore, to be overridden moraines of the former drift. There are other ridges in the vicinity of the Minnesota and International Railroad from Little Fork southwestward for several miles which have a nucleus of Patrician drift and a veneer of Keewatin drift. A few miles farther southwest there is a morainic strip running from northwest to southeast which is crossed by the Big Fork River just below the mouth of Sturgeon River and which runs southeastward on the north side of Big Fork River past Big Falls and thence with slight interruptions to Little Fork River in the east part of T. 65, R. 25W. The same belt reappears between Little Fork and Net Lake rivers and continues southeastward into St. Louis County, passing just south of Net Lake and leading past the south side of Pelican Lake to the west end of Vermilion Lake. This morainic strip seems to have been formed in the main by the Patrician ice field but it carries a somewhat heavy deposit of Keewatin drift. For several miles in the vicinity

of Big Falls and in much of its course gravel and sand deposits are abundant, thus distinguishing it from the ridges farther north which are composed chiefly of bowlder clay.

The highest shore of Lake Agassiz is marked generally by a well-defined gravel ridge or beach. Numerous gravelly ridges are also developed at lower levels, some of which appear as narrow strips of dry land traversing the extensive swamps. These have served as lines for highways across the swamps.

Systematic surveys are being made for draining the swamps of this county (see Plate XIV B), under the direction of the County Surveyor, and roads will be constructed along each of the main ditches thus giving openings to the market for areas of farming land which are at present cut off by swamps.

Estimates have been made from field maps of the percentages of each of the several main classes of land in this part of Koochiching County east of the 94th meridian. Similar estimates given in *Bulletin 12*, page 61, show the percentages of the western part of the county.

Percentages of Classes of Land

	Square miles	Per cent of county
Moraine with sandy to gravelly loam soil	87	4.1
Overridden morainic ridges with clay loam soil	19	0.9
Till plain with prevailing clay loam soil	125	5.91
Lake washed drift with clay loam soil	731	34.57
Lake washed drift with sandy loam soil	42	2.00
Sandy and gravelly deposits of old lake shores	54	2.55
Hilly land with rock near surface	55	2.60
Interior lakes	16	0.75
Swamp lands	985	46.62
	2,114	100.00

The census returns for the entire county show that in 1910 only 3.6 per cent of the land area was in farms, and only 7.5 per cent of the farm land was improved. The rapid growth of International Falls has given a good market for farm products in the north end of the county and farms there are being rapidly developed. The clay loam soil, both in the till plains above the level of Lake Agassiz and in the till which has been washed by the lake, may be developed easily into first-class farm land. It has only a moderate number of bowlders and cobblestones except locally where the underlying stony Patrician drift comes to the surface or has been involved with the more clayey Keewatin drift by the readvance of the Keewatin ice over it.

A. FIRST CROP ON LAND STUMPED THE PREVIOUS YEAR AT EXPERIMENT FARM, DULUTH

B. HEAVY STEEL DISK USED IN PREPARING NEW SOIL

C. WINTER VIEW AT DULUTH EXPERIMENT FARM

A. CULTIVATED RED DRIFT TILL PLAIN NEAR FOLEY

B. RED DRIFT TILL PLAIN WITH FOREST NEAR FOLEY

C. BOULDERS ON RED DRIFT TILL PLAIN NEAR FOLEY

area of the swamps can be greatly reduced at moderate expense and changed into fertile till plains. The soil of the till plains is diversified and ranges from fine clayey loam to a loose-textured stony loam. It was found impracticable to map with any accuracy the extent of each kind of soil in these plains. They are accordingly classed in the table below as till with mixed soil, and represented by the letters TM on the map.

The moraines are very largely of a loose-textured till with a liberal admixture of bowlders and smaller stones gathered up apparently from the Patrician drift which underlies the Keewatin drift throughout this county. In some cases it is thought that the morainic ridges were formed by the Patrician ice field, for they seem to have but a thin veneer of Keewatin drift. This is especially true of those in the eastern part of the county.

The outwash plains are composed of sandy gravel. They are interrupted more or less by scattered knolls and gently undulating tracts with somewhat gravelly material not easily connected into definite morainic belts.

There are numerous places in the northeast part of the county where the relief of ridges is due in part to the altitude of the underlying rock, but there are only a few natural outcrops of rock. The areas in which rock is near the surface are estimated to amount to not more than 25 square miles in the entire county. This includes the places where rock is known to be within a few feet of the surface and the places uncovered by mining, as well as the natural exposures.

The estimates of percentages of different classes of land given in the table below are for the entire county, since only a small part of it was embraced in the estimates given in *Bulletin 12*.

Percentages of Classes of Land

	Square miles	Per cent of county
Moraines chiefly with sandy to stony loam soil	685	24.64
Till plains with variable soil	775	27.88
Gravel plains and other deposits of sandy gravel	225	8.10
Areas with rock near surface	25	.90
Lakes	225	8.08
Swamp lands	845	30.40
	2,780	100.00

The census of 1910 gives 6.2 per cent of the land area of Itasca County in farms, and of this only 12.6 per cent was improved farm land. The farms are developed chiefly along the Mesabi Iron Range in the vicinity of the mining towns. But there are also farming districts south of Grand Rapids, and a few farms are developed along the Great Northern Rail-

A. CORN WITH GOOD SIZED MATURING EAR, AT DULUTH EXPERIMENT FARM

B. CORN SUITABLE FOR ENSILAGE AT DULUTH EXPERIMENT FARM—FIRST CROP

way lines in the southeastern part of the county in the vicinity of Swan River, Goodland, Acropolis, and Bengal. As is natural in this region in the vicinity of mining towns, vegetables form the principal crops, and amount to about 30 per cent of the value, while cereals amount to only 4 per cent. Hay and forage in 1909 constituted 24 per cent of the entire crop values.

EASTERN CASS COUNTY

The part of Cass County west of the 94th meridian has been described in *Bulletin 12*, and an area of about 375 square miles east of that meridian remains to be described herein. This is a strip a little more than 10 miles wide and about 36 miles long. It is crossed centrally by the "Soo" Railroad on which is located the thriving village of Remer, the only village in this part of Cass County. The land surface is flat to gently undulating as far south as Remer and much of it is swampy. This part of the county was covered by the Keewatin ice sheet, and its southern limit was about five miles south of Remer at Big Rice Lake. The border of Keewatin drift deposits runs eastward from there to Shovel lake in Aitkin County. Railway cuts between Remer and Shovel Lake expose the Patrician drift beneath the Keewatin and show the more stony character of the former drift. The greater part of the Keewatin drift has a clayey to sandy loam soil with very few bowlders and cobble stones.

From Big Rice Lake southward past Thunder Lake there is a prominent moraine of the Patrician drift which runs eastward, but becomes overridden by the Keewatin drift near Shovel Lake. It contains hills 50 to 100 feet high and is very stony as well as rugged. South of this moraine is a till plain several miles in width with gently undulating surface. This also is very stony but has a soil of sufficient strength to make excellent grazing land. South of this plain is another moraine running from Crooked Lake northeastward into Aitkin County. This also is rugged with sharp knolls and deep basins and its soil is very stony. A few settlers have located on and near it in the vicinity of Mae post office.

NORTHEASTERN CROW WING COUNTY

A small area of scarcely 250 square miles in the northeastern part of Crow Wing County lies in this quarter of Minnesota. It is a very diversified area, parts of it being strongly morainic, other parts of it gently undulating, and a strip in the vicinity of the Mississippi River which was covered by Lake Aitkin is very flat. The Keewatin ice extended a small lobe down the Mississippi valley into Crow Wing County as far as Rabbit Lake north of Cuyuna, but not more than 35 square miles of this county are covered by that drift. At its southwest end this area of Kee-

watin drift encroaches on a prominent moraine of Patrician drift which crosses the Mississippi River west of Rabbit Lake. The part north of the Mississippi has its western border along Little Pine River, there being an extensive gravel plain west of that stream from Emily southward. The moraine becomes diffuse east of Emily but is traceable northeastward into Aitkin County. The part south of the Mississippi sweeps around the west and south sides of Mille Lacs Lake. A till plain with gently undulating surface and only a moderate number of surface bowlders occupies the district northward from Emily to Outing and thence eastward through the northern edge of Crow Wing County into Aitkin County. Parts of this have a rich loose-textured soil. In the morainic areas there are scattered settlers who have selected the land that has relatively few bowlders and easily cultivated soil. The area that was covered by Lake Aitkin lies mainly south of the Mississippi River and usually has a sandy soil except where covered by peat. The subsoil becomes clayey within the depth of a few feet and in places at only a few inches in depth and the land gives good returns under cultivation.

AITKIN COUNTY

Aitkin County lies mainly in the southwest part of the northeast quarter of Minnesota but extends also a few miles south of the median line of the state and embraces the north half of Mille Lacs Lake, the second largest lake in the state. The entire county is included in the present discussion. Nearly all of it is within the Mississippi River drainage, only a few square miles in the northeast corner being tributary to Lake Superior through St. Louis River. The area of the county is about 1,975 square miles, of which about 200 square miles is occupied by lakes. The area within Mille Lacs Lake is nearly 100 square miles.

A line of the Northern Pacific Railroad running westward from Duluth centrally across the county was for many years the only line of railway in it. But recently three branches of the Soo Line system have been extended across the county, one through the north half, another through the southeast part, and another near the line of the Northern Pacific through the central part. There is also a small railway line running from the Great Northern at Swan River to the thriving town of Hill City in the north part of the county.

Except in the vicinity of Aitkin, the county seat, the entire county is sparsely settled. There is a large amount of swamp land, it being estimated by Ralph that 828 square miles, or about 42 per cent of the county, is too wet for cultivation under present conditions. There are, however, large areas of wet land in the southern half of the county which will need only a slight amount of ditching to get rid of the surplus water after

A. SPRUCE AND POPLAR ON BED OF LAKE AGASSIZ WEST OF COOK

B. MUSKEG IN BED OF LAKE AGASSIZ NEAR BIG FALLS

it has been cleared of brush and timber. The subsoil of these wet tracts is chiefly clay with only a thin cover of peat and muck. The northern part of the county has extensive muskegs with thick deposits of peat, and wire grass marshes with a substratum of sand or silt. The place where these marshes and muskegs are was for some time after the disappearance of the ice occupied by shallow lakes which became drained with the cutting down of the valleys of the Mississippi and St. Louis rivers.

Each of the three drifts, Superior, Patrician, and Keewatin, are present in the county. The Superior drift covers several townships in the southeast part. The Patrician drift is at the surface in the western part of the county and underlies the other drifts in the remainder of the county. The Keewatin drift covers most of the northern half of the county and extends in places a few miles into the southern half. It does not, however, cover the Patrician drift in an area of high land in the northwest part of the county lying south and west of Willow River.

There are several areas of sharply ridged or morainic drift distributed widely over the county and occupying nearly one fourth of its surface. Their distribution may be seen by reference to the general map, Plate I. There are two moraines of the Superior lobe in the eastern part. All the other moraines were formed by the Patrician ice. Those in the northern half were also overridden to some extent by the Keewatin ice. As a result of this overriding the surface has, on the whole, been rendered smoother, but in a few places the later ice movement appears to have shoved up sharp ridges where the surface before had been less sharply ridged.

The sharp knolls and ridges of the moraines are usually composed of gravel and sand and of very stony till. Surface bowlders are also numerous. Such land seems better adapted for grazing than for cultivation, though some good farms have been developed on hills in the southern part of the county.

The level or gently undulating tracts in the midst of the morainic areas, as well as the extensive plains separating the moraines, have usually a productive clay loam soil adapted for agriculture. This is clearly described by Warren Upham who says:

"The areas of till have everywhere a very productive dark soil, a foot or more in depth, in which the proportion of bowlders and gravel is usually not so great as to hinder plowing. This soil is readily permeable to rains, and in dry seasons gradually yields its moisture to growing crops, so that they are rarely or never harmed by the moderate droughts which occasionally occur in summer. Gentle slopes and good natural drainage generally permit early sowing and planting, and the season of growth between the latest frosts of spring and the first in autumn is usually about four months, permitting a great variety of farm crops to be well matured and ripened. Only small parts of the till areas, consisting of morainic ridges and hills, have too abundant boulders and too steep slopes to be available for

cultivation; and these tracts, when cleared, are suitable for pasturage. Hay is a natural product of the district, for portions of many of the streams are bordered by moist lands from a few rods to a half mile in width, bearing a luxuriant growth of tall meadow grasses, which make one to two tons of hay per acre. Many of the swamps now inclosed by higher ground are capable of drainage by ditches and will then rank as the most valuable farming land."[1]

There is a sandy plain covering from 50 to 60 square miles lying north of Mille Lacs Lake in Tps. 45 and 46 N. and Rs. 25, 26, and 27 W. on which numerous farms have been developed. The water table is very near the surface so that the crops are seldom seriously affected by drought. The soil, however, is much lighter than on neighboring till plains to the east. Another sandy area of a few square miles is found at the extreme end of the Superior lobe in Tp. 45, Rs. 23 and 24W. Aside from this the area occupied by the Superior lobe in Aitkin County is nearly all clayey till; under present conditions much of it is wet and swampy, but may be largely reclaimed by ditching. Along the borders of the Mississippi, from the northern end of the county to where the stream leaves it on the west, farms have been developed. The soil is usually somewhat sandy but is underlain to some extent by a fine lake silt that was deposited in the bed of Lake Aitkin. This soil is, on the whole, as productive as the till areas, and has the advantage of being nearly free from stones. The extensive swamps bordering the Mississippi are rapidly changed into productive farm land when the surplus water has been removed by ditching.

The estimates of percentages of classes of land in the table below are necessarily only rudely approximate in the present sparsely settled condition of the county, and, as noted above, the percentage of swamp land will be very greatly reduced with only a moderate amount of ditching as soon as the land is cleared and the obstructions removed from the natural drainage.

Percentages of Classes of Land

	Square miles	Per cent of county
Moraines chiefly with stony to sandy loam soil	464	23.50
Till plains chiefly with clay loam soil	357	18.00
Sandy plains	121	6.10
Lakes	205	10.40
Swamps and marshes and muskegs	828	42.00
	1,975	100.00

According to the census of 1910 only 15 per cent of Aitkin County was in farms, and only one fifth of this, or 3 per cent of the county, was improved land. Corn and oats are the leading cereals and potatoes the

[1] Upham, W. *Aitkin County, Geology of Minnesota* 4:34. 1899.

A. VERY BOWLDERY LAND ON MESABI RANGE NEAR HIBBING. IT ONCE SUPPORTED A GOOD HARDWOOD FOREST

B. ROCKY AREAS IN NORTHEASTERN MINNESOTA. AMONG THE ROCK KNOBS TIMBER THRIVES

leading vegetable. Hay and forage form the principal crop on the farms, and in addition to this there is much wild grass put up as hay. Strawberries and raspberries are important small fruits. Apples and plums are grown successfully as orchard fruits. The prominent hills and ridges in the moraines have a topographic condition favorable for the growth of orchard fruits, since they often escape the frosts that affect the lower lands around them; but as yet very little use has been made of them for orchards.

CARLTON COUNTY

Carlton County is located at the southwest end of the Lake Superior basin, south of the western part of St. Louis County. It has an area of 867 square miles. The eastern portion, comprising less than half of the county, is tributary to Lake Superior, the western part being tributary to the Mississippi, partly through the Kettle River southward into the St. Croix and thence to the Mississippi at Hastings, and partly through Prairie River directly westward into the Mississippi in Aitkin County. Glacial Lake Duluth, which occupied the western portion of the Superior basin, covered fully 150 square miles in the southeast part of the county, chiefly in the basin of the Nemadji River. The St. Louis River enters the area that was covered by Lake Duluth at Carlton and runs near the north edge of that lake area to Lake Superior.

This county was covered by the Superior ice lobe, except a few square miles in the northwest corner in which both the Patrician and Keewatin drifts are exposed. The moraines of the Superior lobe run from northeast to southwest across the portion of the county lying north of the axis of the Superior lobe and the bed of Lake Duluth. The moraines south of the basin and bed of Lake Duluth have a nearly east to west trend in southern Carlton and northern Pine counties. The morainic areas occupy about one third of the surface of the county, not including extensive areas of outwash associated with them, which, together with the lines of glacial drainage embrace nearly one eighth of the county. It is thought that some of the more prominent moraines along the north side of the Lake Duluth area have a nucleus of Patrician drift of morainic character. The trend of the moraines of the Patrician ice sheet here is very similar to that of the moraines of the Superior lobe, but the ice laid on the northwest side of the Patrician moraines, or directly opposite the position which the Superior lobe presented to its moraines in this particular district. The Patrician ice, however, had melted away from its moraines before the Superior ice advanced over them.

There are extensive till plains in the western half of the county covering over 200 square miles. There are also extensive swamps in that

[illegible]

[illegible] the soils and their agricultural [illegible]

The following table presents the percentages of classes of land as determined on the geologic basis. Owing to the lack of roads in certain parts of the county where settlements have not yet reached the estimates are necessarily only rudely approximate.

Percentages of Classes of Land in Carlton County

	Square miles	Per cent of county
Morainic areas outside Lake Duluth chiefly sandy and stony loam	273	31.50
Waterlaid moraines in Lake Duluth	26	3.00
Till plains, clay loam to sandy loam	212	24.40
Gravelly and sandy outwash and glacial drainage	102	11.80
Sandy plains in Lake Duluth	20	2.30
Clayey plains in Lake Duluth	111	12.80

Rock ledges	3½	0.40
Lake areas	9½	1.10
Swamp lands	110	12.70
	867	100.00

The waterlaid moraines in the bed of Lake Duluth have considerable expression for a few miles west from Barker, the topography being nearly as sharp as that of landlaid moraines. In the remainder of the lake area, however, waterlaid moraines are very inconspicuous. They determine to some extent the course of streams tributary to the Nemadji River even where lacking in surface expression.

The census of 1910 reports 21.7 per cent of Carlton County to be in farms, of which 22.8 per cent is improved land. Oats, wheat, and barley are the main cereal crops, rye and corn being grown in less amount. Potatoes are the main vegetable crop. Apples and plums are successful orchard fruits, and berries of all kinds are found very productive. In this county, as well as in other parts of northeastern Minnesota, wild raspberries are very abundant and large numbers of the residents resort to the unappropriated lands for them in the berrying season.

The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY

WILLIAM H. EMMONS, DIRECTOR

IN COÖPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 14

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS OF THE SOUTH HALF OF MINNESOTA

BY

FRANK LEVERETT

AND

FREDERICK W. SARDESON

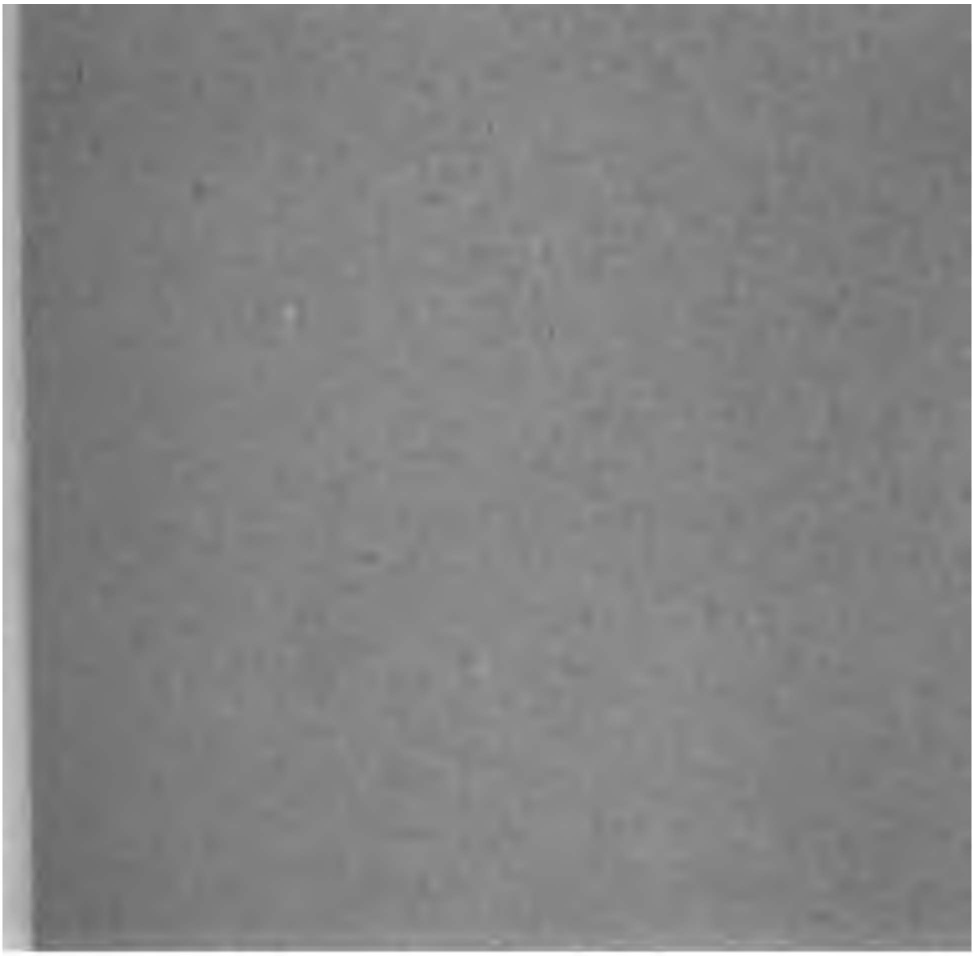
WITH A CHAPTER ON

CLIMATIC CONDITIONS IN MINNESOTA

BY

U. G. PURSSELL

MINNEAPOLIS
The University of Minnesota
1919



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SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS OF THE SOUTH HALF OF MINNESOTA

By Frank Leverett and Frederick W. Sardeson

INTRODUCTION

By W. H. Emmons

Soil is the loose unconsolidated material which nearly everywhere covers the surface of the earth and in which plant life may be maintained. It is made up of finely divided rock in which decaying vegetable matter and animal matter are mingled. A soil is generally in a state of change. It is being washed little by little to the creeks and rivers which carry it to the sea, where it often forms delta deposits; if no new soil formed, hard rock would finally be exposed instead of the loose plant-producing soil. But rocks at and near the surface are continually changing and new soil is being formed from the underlying rock or from loose clayey or gravelly material that may constitute the subsoil, or from bowldery material that at many places in Minnesota lies between the hard rock and the soil.

Water and air attack rock matter and break it down. Heat and cold, freezing and thawing, shatter the rocks and give plants an opportunity to send roots into the cracks that are formed, and these, prying the rocks apart, reduce them to particles of still smaller size. Even the hard solid rocks are ultimately broken down; a building of good solid stone may crumble in a few hundred years, especially in a moist climate.

Some of the rocky matter is dissolved by the water and carried to the sea in solution. It is such dissolved material that makes water "hard" and that gathers in the bottom of a vessel when water is boiled. But not all of the soluble substances are dissolved and carried away; some remain in the soil, and the character of the soil depends largely upon these. Some soils are acid because they have not enough lime. Some are deficient in potash or phosphates, which are necessary if soil is to produce certain crops satisfactorily.

Because it forms the soil, the composition of the underlying material is of great importance. In Minnesota most of the soil is the weathered portion of glacial drift or of lake beds and other features connected with the deposition of the drift. Long ago nearly all of what is now the state of Minnesota was covered over with a great ice sheet hundreds of feet thick that slowly moved down from the Canadian highland carrying with

ALTITUDE

The altitude of Minnesota ranges from 602 feet, the level of Lake Superior, up to 2,230 feet, on high rock hills in the northeast part of the state, in western Cook County. The small map, Figure 1, shows that a large part of the state falls between 1,000 and 1,500 feet. The average altitude of the state is not far from 1,200 feet. The portions above 1,500 feet lie chiefly in two areas, one at the northeast and one at the southwest corner of the state, though there is a good sized area around the sources of the Mississippi River in the western part, and several smaller areas in that vicinity; one of these in the southern part of Otter Tail County is known as the Leaf Hills. The altitude of the elevated area in the southwestern part falls short a little of reaching 2,000 feet, but that in the northeastern part includes several small areas, chiefly in Cook County, that rise above 2,000 feet. The portions below 1,000 feet fall in two areas widely separated except for a connecting line along the Minnesota valley, one being on the western edge of the state and the other on the eastern. There is also a narrow strip bordering Lake Superior.

RELIEF

The most conspicuous relief is found in the "Sawtooth Range" and other prominent ridges that closely border Lake Superior and which rise abruptly from 500 to 900 feet above the lake. The rock ranges lying back from the shore, though more elevated than those fronting on the lake, seldom rise more than from 200 to 300 feet above the swamps and lakes among them. In fact several of the lakes of Cook County are above 1,900 feet or within 300 feet of the level of the highest points in the state. The most prominent part of the Mesabi Iron Range in St. Louis County rises from 400 to 450 feet above bordering plains. The Coteau des Prairies rises about 700 feet above the plain northeast of its border, but in Minnesota the rise is usually spread over a space of from 12 to 15 miles or more in width, so that the elevation can scarcely be appreciated by one crossing over it. There is a rather rapid rise of from 300 to 500 feet to the sharp range of hills in Otter Tail and Becker counties from the Red River valley. This rise is of especial interest since it seems to have some influence on the rainfall, the precipitation being greater in these hills where air currents are forced upward and cooled than in the bordering lower lands to the north, west, and south.

DRAINAGE

The drainage of Minnesota is widely divergent, part of it leading to the Gulf of Mexico, part to the Gulf of St. Lawrence, and part to Hudson Bay. The Gulf of Mexico receives about 57 per cent, the St. Lawrence less than 9 per cent, and Hudson Bay fully 34 per cent of the drain-

decay and carrying the remains of ancient vegetation marks the contact between the older and the younger drift. The boundaries of the drifts of various ages and the character of the soils formed by them are discussed on pages that follow.

Swamps are very numerous in Minnesota. They are portions of the old lake beds and other poorly drained areas and are of little value for agriculture until drained. Since the ice melted a growth of vegetation has been established on them and great thicknesses of partially decayed vegetation have accumulated in them. This forms the peat which is found in so many of the swamps. Some of it is very thick and will doubtless become a valuable asset in the future when other fuels shall have become more costly.

The great productivity of Minnesota soils is due, not only to their recent origin by reason of which nearly all of them still contain the soluble mineral foods for plants, but also to a favorable climate. The low temperatures which frequently prevail during certain periods in winter make for healthful conditions for animal life and they also benefit plant life. The rainfall, though not excessively great, is sufficient and, since most of it occurs during the growing period, drouths are rare and crop failures almost unknown except in the more sandy soils, which are, however, adapted to quick-growing crops like potatoes. As shown herein, the length of the crop-growing season, that is, the time between late spring frosts and early autumn frosts, is between 100 and 170 days for all except the extreme northeast corner of the state. The long days, high proportion of sunshine, and the moderate humidity are all favorable to plant growth.

This bulletin treats the soils of only the south half of Minnesota. The field embraced includes the part of the state south from the median line, which is near latitude 46° 25′.

Following the plan in *Bulletin No. 12,* on Northwestern Minnesota, a brief general description of the surface features and deposits of the entire state is given, and the climate of the entire state also is discussed. It will be followed by a report on the entire state, the field work for which already has been completed. The work has been done in accordance with the agreement for coöperation between the United States Geological Survey and the Minnesota Geological Survey, entered into, March, 1912. By this agreement the services of Mr. Frank Leverett were secured for surveying the surface formations and soils. Mr. Leverett has been engaged since 1886, or thirty-two years, in studying the surface geology of the Great Lakes region and because of his large experience in the greater area he was particularly well prepared to undertake the studies in Minnesota. He has spent, moreover, considerable time in the state studying its

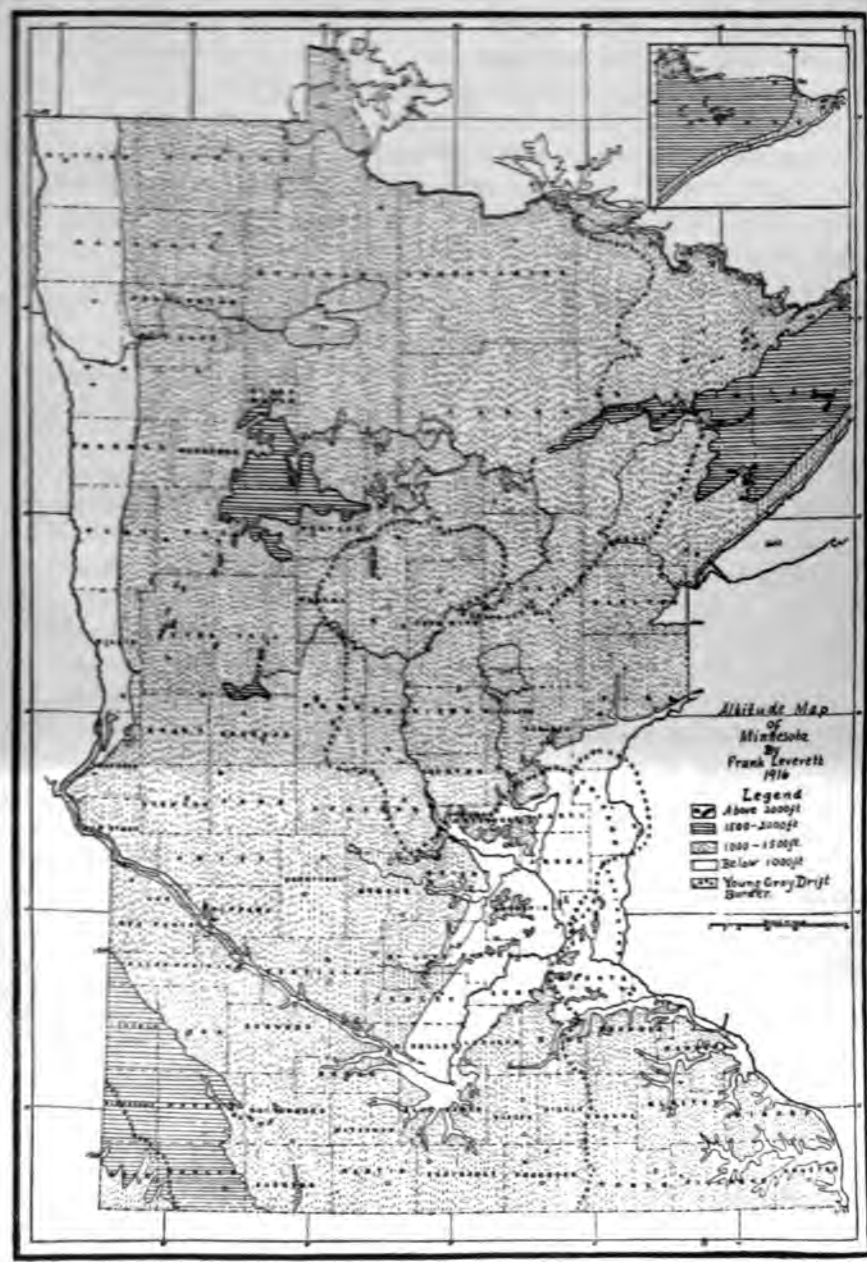

FIGURE I. ALTITUDE MAP OF MINNESOTA

CHAPTER I

PHYSICAL FEATURES OF MINNESOTA

TOPOGRAPHY OF MINNESOTA

GENERAL STATEMENT

The position of Minnesota is near the center of the North American Continent, and the state embraces an area of 84,682 square miles, of which about 93 per cent is land and 7 per cent water. Its extreme length is nearly 400 miles, from latitude 43° 30′, at the Iowa line, to a point about 23 miles north of the 49th parallel, in the projection known as the Northwest Angle, northwest of Lake of the Woods. The greatest width is 367 miles, but the average width is only about 225 miles, or but little more than half of the length.

Minnesota presents more variety in surface features than most of the north central states, yet a great part of its surface is level or only gently undulating. The flattest portion falls largely in the northwest quarter, and was once the bed of the glacial Lake Agassiz, a lake held in on the north, in central Canada, by the great ice sheet. The roughest portion is in the northeastern quarter. This part is composed largely of volcanic formations and iron-bearing rocks which, though glaciated, were not everywhere buried beneath the glacial deposits. In the southeastern part of the state deep erosion valleys along the Mississippi and its tributaries present bold rock bluffs 300 to 600 feet high. The interior and southern parts of the state have features due almost entirely to the work of the great ice sheets, which at successive times, and from different directions, overspread Minnesota. The glacial deposits comprise an intricate system of moraines with undulating to hilly surface, associated with which are level outwash plains of sand and gravel, and gently undulating intermorainic till plains. The moraines were formed along the border of the ice at definite lines where the edge of the ice held its position for a relatively long time. They consist of sharp knolls and inclosed basins and also of more or less parallel ridges which, however, interlock in places. These moraines are distributed in rudely concentric systems which mark successive positions of the border of each ice sheet as it was melting off from this region. The outwash plains lie on the outer border of the moraines, where sandy gravel was spread out by dirt-laden waters escaping from the ice. The till plains lie along the inner or iceward border of the moraines and represent areas over which the ice border melted back somewhat rapidly, forming relatively few knolls and ridges.

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First. Residuary material.
Second. Wind deposits.
Third. Glacial deposits.
Fourth. Stream deposits.
Fifth. Lake deposits.

RESIDUARY MATERIAL

The residuary material, as its name implies, has been left as a residue during the breaking down or decay of the surface rocks through weathering and solution. On limestones it is usually a dark, reddish brown, gummy clay, but on sandstones and crystalline rocks it is usually granular and loose-textured. There is but a small part of Minnesota, chiefly in the southeastern counties, where residuary material is within reach of the plow. It occurs there on the upper part of the slopes of the valleys and on the narrow upland strips between valleys, but it is usually covered by loess.

WIND DEPOSITS

Loess.—The wind-deposited material known as loess is largely a fine silt loam, which forms the surface in an area in the southeast part of the state embracing much of Goodhue, Olmsted, Wabasha, Winona, Fillmore, and Houston counties and parts of Mower, Dodge, Rice, and Dakota counties. It covers a small tract in the southwest part of the state. In the southeastern counties it rests in part on glacial drift deposits and in part on the residuary clay and rock formations of the driftless area. In the southwestern part it covers glacial deposits. In the southeast district its border is very irregular, there being long strips of loess-covered land projecting westward or northwestward into the region free from loess, and also long strips free from loess extending eastward into the loess-covered tracts. The condition there is such as might result from the presence or absence of vegetation giving different degrees of protective power from the wind; areas with dense vegetation being able to hold dust that settled from the atmosphere while bare ones allowed it to be gathered up and carried on.

Wind-blown sand.—Wind-blown sand is also an important deposit. It embraces a district east of the Mississippi from Minneapolis up to Brainerd. It is narrow above St. Cloud, but below that city extends eastward to the St. Croix River. The sand does not, however, cover the entire surface in this area. Where present it rests upon glacial deposits. It has low ridges seldom 20 feet and usually 10 feet or less in height. There is more or less wind-drifted sand in the sandy parts of the St. Louis River drainage basin, but it is sparingly developed compared to

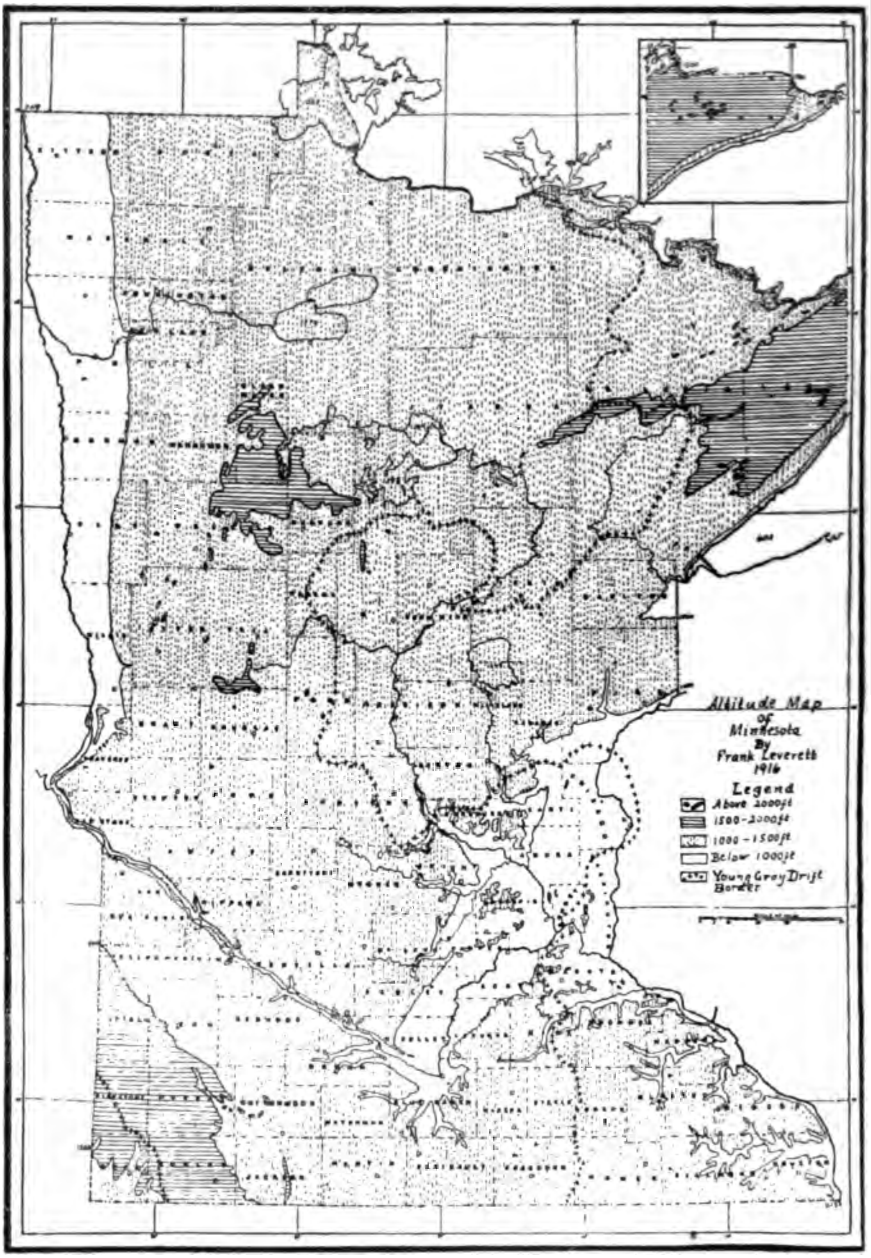

FIGURE I. ALTITUDE MAP OF MINNESOTA

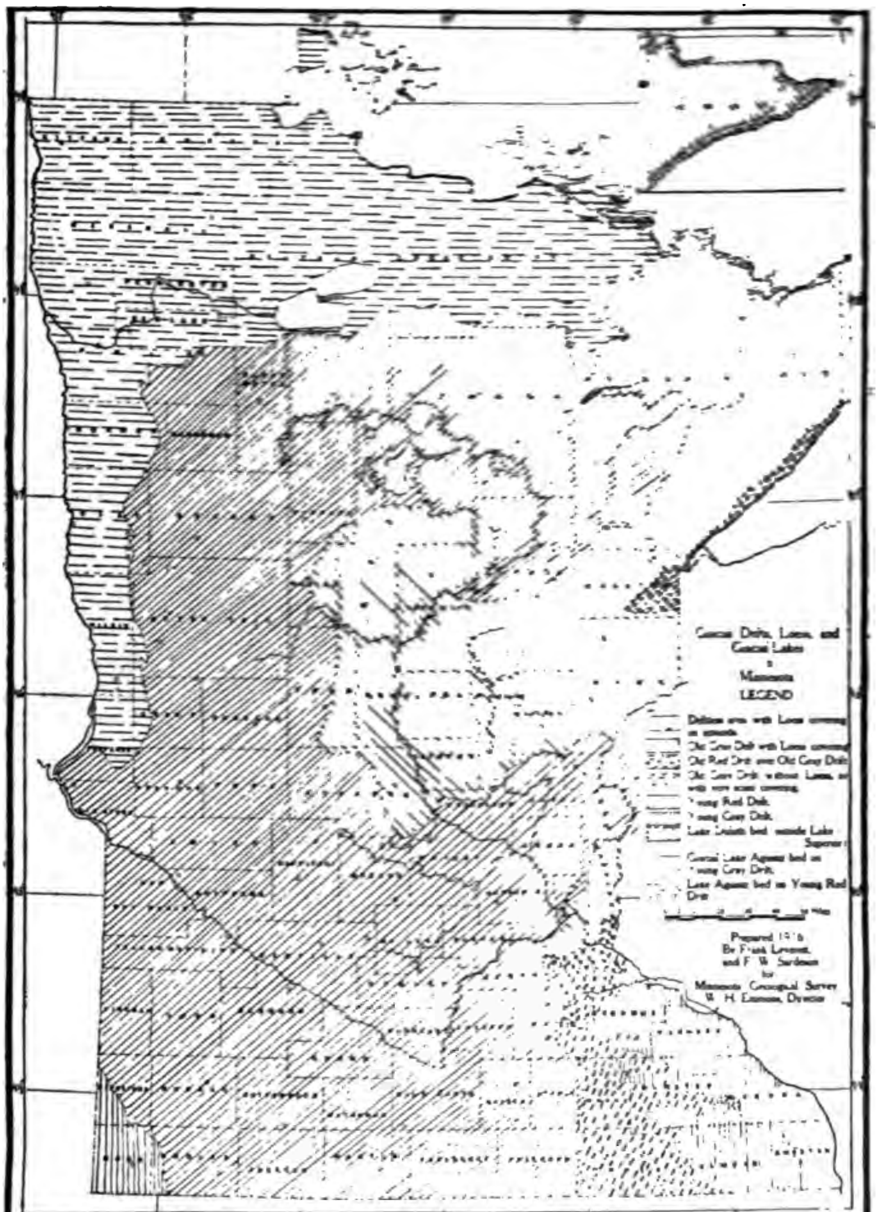

FIGURE 2. MAP OF GLACIAL DRIFTS, LOESS, AND GLACIAL LAKES IN MINNESOTA

STREAM DEPOSITS

The stream deposits, being restricted to the valleys, are of limited area, though in such valleys as the Minnesota and Mississippi they are locally several miles in width and form important agricultural belts. On the Minnesota and the part of the Mississippi below the confluence with the Minnesota the deposits made by the rivers are sand or silt. On the Mississippi above the mouth of the Minnesota the deposits range from sand to coarse cobble and bowlders in correspondence with the swiftness of the stream. On nearly all the tributaries of the Mississippi and Minnesota the streams are able to carry coarse as well as fine material. Along the Red River a considerable amount of fine clay and clay loam has been deposited in seasons of flood on the plains outside the immediate river channel. The deposits made by glacial streams or those which had their sources at the edge of the ice and were receiving much of their water from the melting ice, now appear usually as terraces along the valleys above the limits of floods. From the fact that the glacial rivers were of greater volume these deposits are generally composed of sandy and gravelly material somewhat coarser than that carried by the present rivers.

LAKE DEPOSITS

The lake deposits consist of fine sediments washed into the deep parts of the lakes, and sandy and pebbly deposits washed up and formed into beaches along the shores. In parts of the lakes where the glacial deposits which they covered were pebbly and the water was shallow enough for wave action, there was a concentration of stony material by the washing-out of the finer material. By this process considerable areas of the bed of Lake Agassiz were covered by very pebbly beds several inches in depth. They are classed on the soil maps as "lake-washed till." In the narrow strip along the shore of Lake Superior that was covered by the waters of a glacial lake known as Lake Duluth, there is very little fine sediment; gravelly and cobbly beaches were formed at several successive levels, while fine material was washed down into the deeper parts of the basin covered by the present lake. Fine material also covers the old lake plain in Carlton County and a strip on the south side of Lake Superior.

THE GLACIAL FEATURES AND THEIR HISTORY

It has been found through a study of the deposits in Minnesota and neighboring states that the glacial deposits which form so extensive a mantle in Minnesota are the result of more than one invasion of the ice from the Canadian highlands. At each invasion the ice left a deposit of drift gathered partly from Canada and partly from the deposits over which it passed in Minnesota. The advances were so widely separated

in time that the drift deposits of one invasion had large valleys cut in them by the action of streams before the next invasion occurred. The later advances failed to reach the limits of the earlier deposits, so they are still exposed to view, and the degree of erosion of the surface of the older can be compared with that on the surface of the younger deposits. It is found that the older drifts have been so greatly eroded and are so ramified by drainage lines that no lakes or undrained basins remain on them, while the younger drift deposits have numerous lakes and undrained basins and also large, poorly drained areas which the streams have not yet reached. It is because they are not covered by the latest drift that Rock and Pipestone counties in southwestern Minnesota, and Goodhue, Dodge, Wabasha, Olmsted, Winona, Fillmore, and Mower counties in southeastern Minnesota have no lakes and basins such as characterize neighboring counties that were covered by that drift.

The invasions of the ice into Minnesota not only took place at different times, but have come from more than one direction at about the same time. In the earlier invasions the greater part of the state was covered by ice coming from Manitoba as shown by limestone fragments and pebbles derived from rock formations of that country which are imbedded in the lower part of the drift over all of the state except its northeast part. The movements in the closing stage of the glacial epoch were more largely from the northeast, but more than half of the state was invaded from the northwest. The ice sheets were as follows: 1. *The Superior lobe of the Labrador ice sheet,* an extension of ice southwestward from the Superior basin nearly to Mille Lacs Lake; 2. *The Patrician ice sheet,* with southward movement from the highlands north of Lake Superior across eastern Minnesota to points a little beyond St. Paul; 3. *The Keewatin ice sheet,* which moved southward through Manitoba and across western Minnesota. After the melting away of the ice that came from the northern highlands, the Keewatin ice sheet extended over some of the ground that ice had vacated. It crossed the Mesabi Range into the St. Louis basin, and also moved northeastward from near Minneapolis into Wisconsin. This advance over earlier drift deposits is known from the presence of a thin deposit of clayey and limy drift containing rock material brought from Manitoba which covers the drift that was deposited by ice coming from the highlands northwest of Lake Superior. The drift from these highlands together with that from the Lake Superior basin forms the stony red drift of eastern Minnesota, while that from Manitoba forms the clayey and limy gray drift which covers almost all of the remainder of the state.

That the ice mass moved in different directions at different times in certain parts of the state is further shown by striations or ice markings

that in the district between the Mississippi and St. Croix rivers. Wind-blown sand occurs also in Aitkin County in the vicinity of McGregor and also in the northeastern part of the county in island-like tracts that are surrounded by marshes. There are numerous small areas of such sand scattered over the state, some of them being along the shores of the glacial Lake Agassiz.

GLACIAL DEPOSITS

The glacial deposits as shown in Figure 2 extend over the entire state except eastern Winona County and the greater part of Houston County, which are in the driftless area of the upper Mississippi. They underlie the wind-deposited sands and much of the loess area. They also underlie stream deposits and lake sediments. The glacial deposits are separable into till or bowlder clay in which stones, clay, and sand are closely commingled; and into sand or gravel beds which show some assorting and bedding by water action. The percentage of stony material varies greatly and the matrix also shows variations from compact clay to loose sand. These variations are to be expected in a deposit that had been formed from the dirt and stones included in an ice sheet. Every observing farmer has probably noted and perhaps speculated upon the cause for these variations in the drift deposits which form the basis for so large a part of the Minnesota soil. The assorted sand and gravel beds are largely due to waters escaping from the melting ice and many of them may be traced up to a moraine which marked the position of the ice border at the time they were laid down. They show a decrease in coarseness in passing away from the edge of the moraine, the coarse material having been dropped close to the edge of the ice and only the fine carried to a great distance outside.

The glacial deposits also show some variations that relate to the kind of rock formations over which the ice passed. Thus, the northeastern portion of the state has a rather stony drift from the volcanic and hard crystalline rocks of that region. This stony material was carried as far south as Dakota County and forms the red drift of eastern and northeastern Minnesota. As indicated below, the red drift is the product of more than one ice sheet. The western and southern parts of the state have a large amount of clayey drift material with limestone pebbles imbedded. This material was gathered by this ice as it passed in its southward course from the shales and limestone of southern Manitoba, into the area of granite and other crystalline rocks. These clayey and limy deposits form what is known as the gray drift of Minnesota, and the ice sheet which formed it, as the Keewatin ice sheet.

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on the surfaces of the rock ledges. In the district east and south of the Lake of the Woods a set of glacial grooves or ice markings bears west of south, while a newer set crosses them in an eastward or southeastward direction. The older set was formed by ice moving into Minnesota from the highlands that lie between Lake Superior and Lake Winnipeg, while the younger set was formed by ice moving into the state from Manitoba. In North Minneapolis there are rock ledges on which the glacial grooves have three courses; first, a southeastward course at the time when the old gray drift which came from the northwest was brought in; second, a southward course at a time when the red drift which came from the north was deposited; third, an eastward course at the time when the ice from the northwest advanced over land that had been vacated by the ice which deposited the red drift.

GLACIAL LAKE FEATURES

Minnesota contains parts of the beds of two large glacial lakes: Lake Duluth, which occupied the western part of the Superior basin, and Lake Agassiz which occupied the Red River basin. Lake Duluth covered a narrow strip along the shore of Lake Superior and extended a few miles beyond the west end of Lake Superior into eastern Carlton County, Minnesota. Its highest stages were 500 to 700 feet above the present surface of Lake Superior, there being an increasing height toward the northeast corner of the state. Lake Agassiz extended as far south as Lake Traverse, and thence it discharged past Brown Valley to the Minnesota. Its border is only from 20 to 30 miles east from the North Dakota–Minnesota line from Lake Traverse northward to Polk County. About 20 miles east-southeast of Crookston it makes an abrupt eastward turn and continues eastward past the south side of Red Lake and on across Koochiching County into St. Louis County as far as the valley of Little Fork River. It then turns northward and enters Canada from northeastern St. Louis County. There were several islands in it in northern St. Louis County.

Preceding the development of the large glacial Lake Agassiz there was a temporary ponding of waters in front of the ice in Koochiching, Itasca, and St. Louis counties at a level higher than that of Lake Agassiz, and a discharge of the waters southward across the Mesabi Iron Range into the St. Louis basin along the course of the Embarrass River. With the melting back of the ice border this lake became merged with Lake Agassiz, and its waters then discharged into the Minnesota valley.

In the Crow Wing drainage basin a glacial lake, Lake Wadena, covering much of Wadena County, and parts of Hubbard, Cass, Morrison, and Todd counties, was held up by the Patrician ice sheet, which covered the lower course of Crow Wing River below Pillager. Its outlet was

southward from Long Prairie to the Sauk River drainage. Outwash plains near Pillager terminate abruptly at the edge of this lake at an altitude of about 1,300 feet, or nearly 150 feet above the adjacent part of the plain on Crow Wing River that was covered by the lake (see Pillager topographic map). This was the deepest part of the lake. In much of its area the waters were very shallow. This lake area was later encroached upon by the Keewatin ice sheet, so its shore lines are obliterated except along the eastern side. Its outlet has also been filled by gravel deposits from the Keewatin ice sheet for a few miles south from Long Prairie.

There were also two noteworthy temporary lakes in northeastern Minnesota which were not held up by ice barriers, but instead by land barriers along their outlets. When these were cut away the lakes became drained. One of these, named Lake Aitkin by Upham, occupied the plain bordering the Mississippi in Aitkin County and extended a short distance into eastern Crow Wing County. It was drained by the erosion of the Mississippi valley at its lower end just above Brainerd. The other lake, named Lake Upham by Winchell, occupied a considerable part of the St. Louis basin in western St. Louis County. It was drained by the erosion of the St. Louis valley below Floodwood.

Prominent features of the two great glacial lakes, Lake Agassiz and Lake Duluth, are the beaches or ridges of sand and gravel washed up along their shores. The shores of Lake Agassiz stand high and dry above the flat parts of the lake bed between or below them and form excellent lines for highways. For this reason much of the pioneer settlement and travel was along these ridges. They generally stand from 5 to 10 feet above the bordering plains and occasionally from 15 to 20 feet. On the inner or lakeward side they are generally more prominent than on the outer or landward side. This is due in part to the original slope toward the center of the lake, but there is also a tendency for a lake to eat back into the bordering land and throw its coarser material up on the edge of the plain outside; at the same time the fine material is carried in suspension from the shore into the deeper water.

The levels of these glacial lakes were lowered from time to time, partly by the cutting-down of the outlets and partly by an uplift of this region which caused the water to fall away where the land rose. There was also a change of outlet in Lake Agassiz from the southern end to the northern and in Lake Duluth from the southward outlet into the St. Croix River to an eastward outlet into the Lake Huron basin. As a result shore lines were formed at various levels on the slopes of the old lake beds. Because of the gradual lowering of the water level the greater part of the beds of these glacial lakes has at some time been

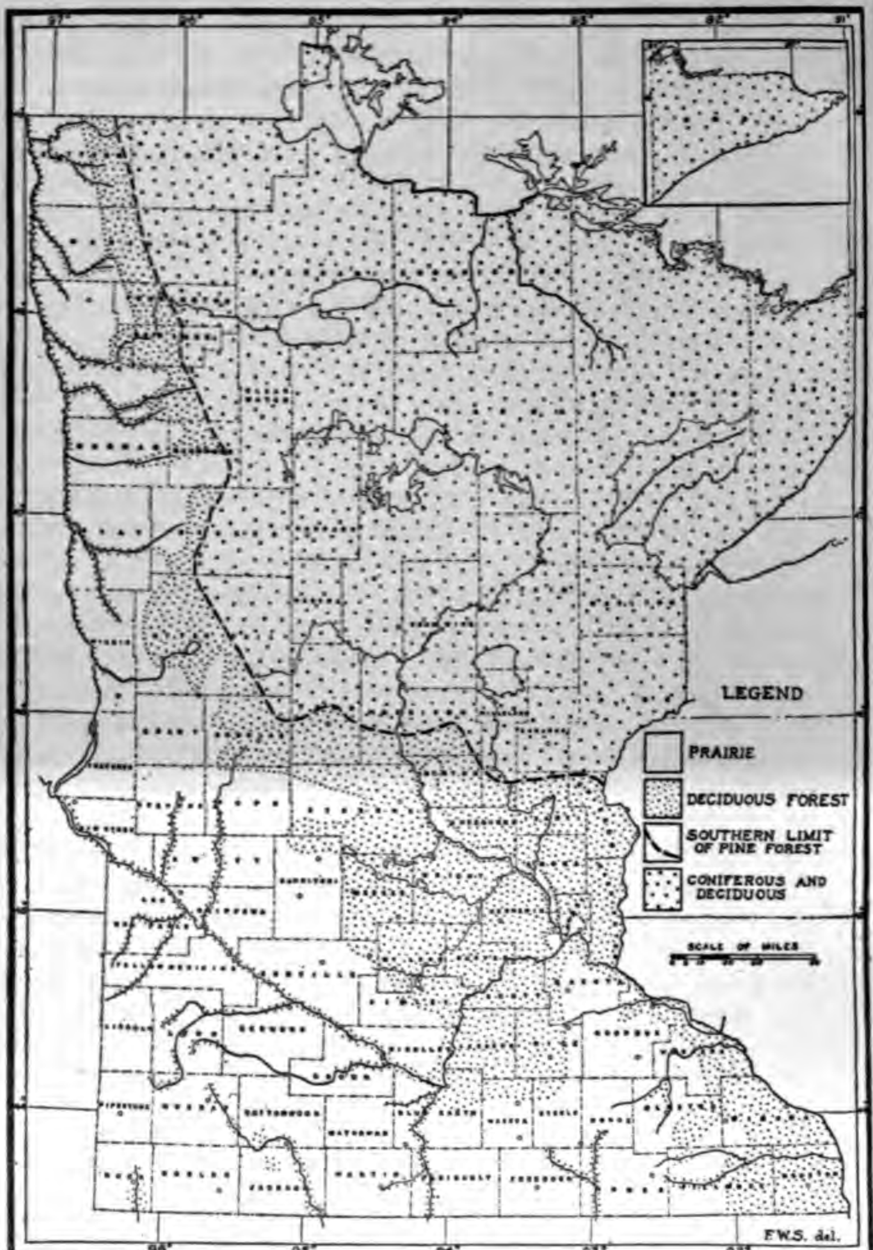


FIGURE 3. MAP OF MINNESOTA SHOWING DISTRIBUTION OF FOREST AND PRAIRIE. (AFTER MAP BY WARREN UPHAM AND BY FREDERIC K. BUTTERS)

Weathering in the loess-covered areas is moderately deep, as it is in the older drift. The entire deposit of loess, however, is of fine texture and is found to be very fertile from top to bottom.

LIME

While most of the soils of the northwestern part of the state seem abundantly supplied with lime, it is probable that some of the more sandy ones would give a sufficiently greater yield of certain crops to make it profitable to purchase some form of lime if this could be obtained at a low price. Usually when a soil needs lime, it is advisable to apply one ton or more of ground limestone or marl per acre. If this has to be shipped any considerable distance, the freight charges may greatly exceed the cost of the material on board of the cars at the point of shipment. For this reason it is important to locate a supply as near as possible to the place where it is to be used.

Lime occurs abundantly in two forms in Minnesota: as bog-lime or marl, and as limestone. The marl is unconsolidated and easily pulverized. It needs no crushing or grinding. Limestone is consolidated and must be crushed or ground for use on fields.

Marl is found in Minnesota in many lakes and under some bogs that have been lakes. It is of most frequent occurrence in the central and north central part of the state. It lies always in low wet ground and can be found, as a rule, only by boring or ditching. It is a soft, white or gray, chalky material. Since it needs no crushing or grinding, the cost of the marl is in the finding, ditching and draining, or drying of it. Deposits from 1 to 10 feet in thickness and covering from 1 to 100 acres are known to be of common occurrence.

Limestone formations outcrop in the bluffs along the Mississippi and its tributaries in southeastern Minnesota. The formations lie horizontally and are of wide extent, or practically continuous for many miles. Limestone formations 100 feet or more thick extend along the valleys from the southeastern corner of the state to Stillwater, Minneapolis, Mankato, Austin, and intermediate points. An inexhaustible supply of limestone is easily found in outcrops that are high, so that quarrying, crushing, and loading can all be done in a down-hill direction, the cost of production being thereby lessened.

EFFECT OF FIRES

There are large areas in Minnesota which have been swept by forest fires, and these fires have destroyed much of the accumulated leaf mold. In sandy areas the destruction of the leaf mold may have reduced somewhat the productiveness of the land, for the leaf mold acts as a mulch to prevent the drying out of the soil. But in clayey areas there seems to

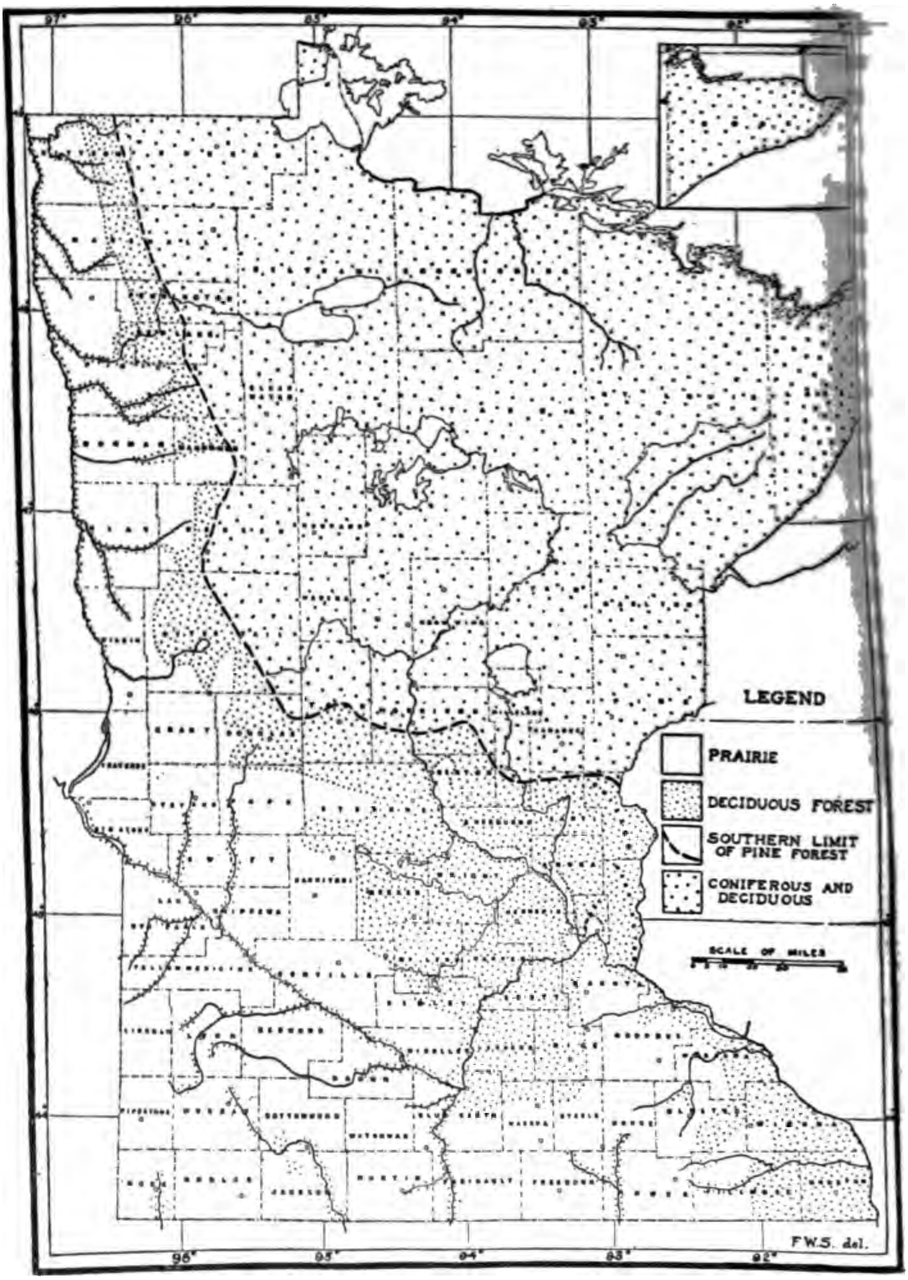


FIGURE 3. MAP OF MINNESOTA SHOWING DISTRIBUTION OF FOREST AND PRAIRIE. (AFTER MAP BY WARREN UPHAM AND BY FREDERIC K. BUTTERS)

This county is largely occupied by the great morainic system formed on the east side of the Keewatin ice field, and has a knolly surface inclosing numerous small lakes and peat bogs. The western end of the county is a till plain, a continuation of the great plain bordering the Minnesota valley. There are also small till plains inclosed among the morainic ridges. Outwash plains open into the Minnesota valley, and the discharge of glacial waters was thence northeastward to the Mississippi.

The forests and lakes give a pleasing scenic effect and attractive setting for suburban residences. The county is traversed by several railroad lines leading direct to Minneapolis, and thus is likely to have in the near future a considerable suburban population. It is also favorably situated for quick marketing of produce, and much loose textured soil suitable for gardening. Thus far, however, it has been chiefly a grain and hay producing county. The till plain in the southwest part of the county has a rich black clay loam soil with pebbly clay loam subsoil.

Percentages of Classes of Land in Carver County

	Square miles	Per cent
Gray drift moraines, pebbly clay loam to gravelly loam soil	140	37.23
Outwash plains of sandy and gravelly loam	11	2.93
Till plains, chiefly of pebbly clay loam	180	47.87
Marshes and bogs on uplands	20	5.32
Sandy bottoms and terraces of Minnesota valley	15	3.99
Wet bottoms of Minnesota valley	10	2.66
	376	100.00

Farm and Crop Data for Carver County from Census of 1910

Rural population 11,247 or 30 per square mile	
Per cent of land area in farms	89.9
Per cent of farm land improved	59.4
Average acres per farm	108.6
Average improved acres per farm	64.5
Value of all farm property	$20,370,744
Per cent of increase 1900 to 1910	118.0
Value of all crops in 1909	$2,264,655
Cereals (wheat, corn, oats, barley, rye)	$1,571,048
Other grains and seeds	$1,717
Hay and forage*	$400,851
Vegetables	$88,846
Fruits and nuts	$39,518
All other crops	$162,675

* Tame grass, 46,934 tons; wild grass, 29,890 tons.

SCOTT COUNTY

Scott County is situated on the east side of Minnesota River with Shakopee as the county seat. The drainage is northwestward to the Minnesota River, except a few square miles in the southeast part which drain eastward through Vermilion River to the Mississippi. The Minnesota valley is over 200 feet in depth, the river being below 700 and the

have been very little reduction of the fertility. The leaf mold in such places, however, when turned under has a beneficial effect in loosening the stiff clay. A large area of clay land in the Little Fork drainage basin in St. Louis and southeastern Koochiching counties was burned over some fifty or more years ago, according to statements of the Indians, and the leaf mold was almost completely destroyed. A heavy growth of poplar has sprung up on the drier parts instead of the mixed hardwood that had occupied the land, while the wet areas have a fresh stand of spruce. This district is being rapidly cleared and is producing exceptionally good crops. The forest fire near Hinckley in Pine County, which occurred about twenty-five years ago, swept over an area chiefly of till much of which is loose-textured. This had a similar effect in changing the forest from mixed hardwood and pine to poplar. This area is now one of marked agricultural fertility adapted to a variety of crops. The principal damage by fire in this state, both past and prospective, seems to be in the destruction of peat in the bogs. In such cases there is not only the loss of a valuable fuel, but the land is left in a rough state ill-suited for cultivation.

CHAPTER II

CLIMATIC CONDITIONS OF MINNESOTA

BY U. G. PURSSELL

Director of the Minnesota Section of the United States Weather Bureau

INTRODUCTION

The agriculture of any region is controlled by its climate. In some parts of the world temperature is the main factor in determining the limits of growth of certain kinds of crops; in others it is rainfall, and in still others it is the amount of sunshine. All of these factors are important in influencing the crop yield even in districts where the general climatic conditions are satisfactory for the growth of plants. In Minnesota these elements are so favorable that a majority of the crops common to the temperate zone may be successfully grown, and a failure of all the important crops is very rare even over a small portion of the state.

Rainfall is an important factor for most crops in the state, because the proper amount of water in the soil at the critical period of development of the plant is necessary to produce a large crop. The length of the growing season also is important and probably no other factor in the study of climate from the standpoint of the agriculturist should be given more consideration. This is the key to an actual knowledge as to the possibilities of success or failure in the production of crops since in parts of the state crops are menaced by frost at some period of their growth, whereas sunshine and moisture seldom vary in Minnesota beyond safe limits.

The factors which determine the climate of any area are the relative distribution of land and water, the topography of the land surface, and the situation of the area in question with relation to the general movement of the cyclones and anti-cyclones.

The position of Minnesota at the center of North America gives it a climate that is largely continental. In continental climates the temperature extremes are greater and the humidity and rainfall generally less than at places near large bodies of water, such as border on the Atlantic, Pacific, and Gulf coasts of the United States. The effect of winds from great bodies of water is to equalize temperatures of lands near by and to lengthen materially the crop-growing season. This is particularly true of the country in the vicinity of Lake Superior, where the influence of that great inland sea in modifying the cold anti-cyclones

gives to that section a more equable climate than would otherwise obtain in that portion of the state. The summer temperatures are likewise modified and people from long distances inland in steadily increasing numbers are establishing summer homes about the lake, to which they are attracted during the hot summer months. There are more than 7,000 small lakes scattered throughout the state and these have a material local influence in modifying the heat of summer and give comfort to thousands of residents on their shores.

Monthly and annual reports of temperature, rainfall, snowfall, etc., have been published for a large number of regular and coöperative stations in Minnesota since 1895. Recently three special section reports have been issued by the United States Weather Bureau giving monthly and annual precipitation totals for all points in the state with a record of ten years or over, together with average temperatures and other data. In these reports the more important facts from all portions of the state are tabulated and the comparative climatic conditions of the different sections graphically shown.

GENERAL CLIMATIC CONDITIONS

Minnesota is in the path of a large proportion of the low-pressure areas which move across the United States from west to east. These areas move at an average speed of 600 miles in twenty-four hours and are preceded by southerly winds and higher temperature and followed by northerly winds and lower temperature. They are usually accompanied by cloudy weather and precipitation; each storm causing an average of from one to two rainy days as it crosses the state.

As there is an average of almost two of these storms each week with fair weather periods between, it follows that the changes in weather conditions are rather rapid. One or two days of stormy weather preceded by fair weather and followed by clearing and lower temperatures to be repeated in turn, make up the usual routine for the week. However, Minnesota is so far from the coast that damaging ocean storms lose much of their severity before reaching its borders.

The northwestern cold waves pass across the state and send their health-giving winds into all parts, and yet they are frequently not so severe as they are in some of the plains states in the same latitude or even farther south.

Temperature.—The average annual temperature of Minnesota for the period 1895 to 1913 inclusive, is 41.7°, as shown in Table I and graphically by Figure 4. The highest annual mean temperature, 43.9°, occurred in 1900, and the lowest, 39.9°, in 1912. The departure of the average temperature of any year from the normal may readily be deter-

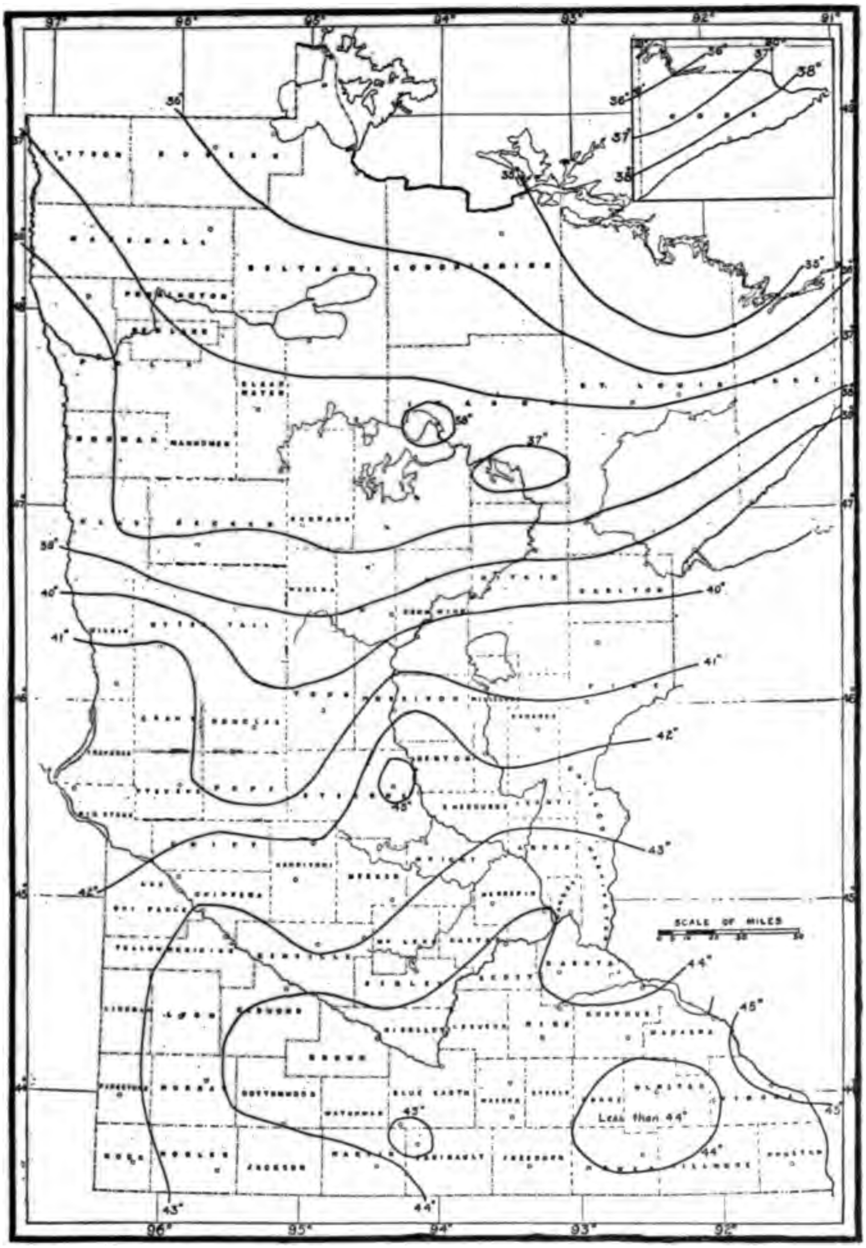


FIGURE 4. MAP SHOWING MEAN ANNUAL TEMPERATURES OF MINNESOTA (DEGREES FAHRENHEIT)

mined by comparing the yearly average with the mean at the foot of the column.

Table I. Monthly and Annual Mean Temperature for Minnesota (Degrees Fahrenheit)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1895	.....	.....	.....	49.9	56.9	64.6	67.8	67.4	61.5	41.4	27.8	18.3	......
1896	12.3	17.9	21.4	44.5	60.9	66.5	69.9	67.9	54.3	42.4	18.0	20.3	41.6
1897	7.2	15.3	20.7	43.7	55.2	62.5	71.6	64.2	65.3	50.0	26.6	12.3	41.2
1898	18.3	16.4	30.3	43.5	55.6	67.0	69.8	66.9	60.6	42.9	26.6	11.9	42.2
1899	9.9	4.5	14.7	44.0	55.1	65.4	70.2	69.1	56.4	49.0	39.6	17.9	41.2
1900	18.4	5.2	23.4	49.5	59.9	66.8	68.8	74.3	58.2	55.1	25.4	18.6	43.9
1901	13.2	10.0	27.3	46.7	58.2	65.5	74.7	69.8	57.3	49.2	28.8	13.0	42.8
1902	15.9	15.5	34.0	42.6	57.0	61.3	69.7	65.2	55.2	47.1	33.3	12.6	42.6
1903	11.3	10.6	29.6	43.3	55.7	62.3	67.2	63.6	55.5	46.1	27.3	9.8	40.3
1904	4.5	2.3	24.8	38.8	55.4	63.2	66.0	64.9	57.4	47.4	36.7	16.7	40.1
1905	5.6	8.9	33.7	42.0	52.6	63.0	67.3	68.9	61.9	43.5	33.1	20.6	41.5
1906	17.0	13.8	20.6	47.9	53.7	63.7	68.3	68.7	63.3	45.7	30.7	15.9	42.0
1907	3.8	14.8	28.7	34.7	45.5	63.3	68.2	66.1	55.9	45.4	31.7	21.3	40.1
1908	16.4	17.9	26.4	45.2	53.9	62.5	69.4	65.5	64.2	47.0	33.8	17.5	43.4
1909	10.5	13.7	26.1	35.8	53.2	65.0	69.2	70.9	58.7	44.7	33.8	10.0	41.0
1910	11.8	7.5	41.7	48.0	51.6	67.8	70.6	65.8	58.4	50.8	25.3	14.7	42.8
1911	5.4	16.6	32.7	42.7	59.8	69.7	68.2	64.0	56.7	43.4	20.2	19.4	41.6
1912	—6.7	10.6	19.8	45.5	55.9	62.5	68.5	63.9	57.2	47.5	33.9	20.0	39.9
1913	7.2	8.6	20.4	46.4	52.7	67.4	67.3	69.2	58.6	42.7	36.9	26.1	42.0
1914	16.9	2.8	26.6	41.2	57.6	64.6	72.4	66.1	60.0	52.6	33.0	9.0	41.8
Mean....	10.5	11.2	26.5	43.8	55.3	64.7	69.3	67.1	58.8	46.5	30.1	16.7	41.7

The coldest month is January, which has a mean temperature of 10.5°, although the average for February is only 0.7° higher. In a great many instances February has averaged colder than the preceding January. This condition occurred in the seven successive years from 1898 to 1904 inclusive. Average January temperatures are plotted on Figure 5.

July is the warmest month, with an average temperature of 69.3°, although in a few years the mean temperature for June or for August is higher than for July of the same year. Average July temperatures are plotted on Figure 6.

The highest summer mean, 70.0°, occurred in 1900 and 1901 (Table II). The coldest summer was that of 1903, with an average of 64.4°.

The warmest crop-growing season (April to September inclusive) of the eighteen years under discussion was in 1900, when the average was 62.9°, and the coldest was in 1907, with an average of 55.6°.

The warmest winter (December to February inclusive) was in 1907-8, when the mean temperature was 18.5°. The coldest was in 1903-4, with a mean temperature of 5.5°. Table II shows also the warmest and coldest spring and autumn.

In Figures 7 and 8 are shown the highest and lowest temperatures ever recorded in the various counties where records have been kept. From these figures it can readily be seen that the extreme range of temperature is from 110° in Kandiyohi County and Milan, to —59° at Leech Lake Dam and Pokegama Falls. Temperatures above 100° have been recorded in all counties except those about the headwaters of the Missis-

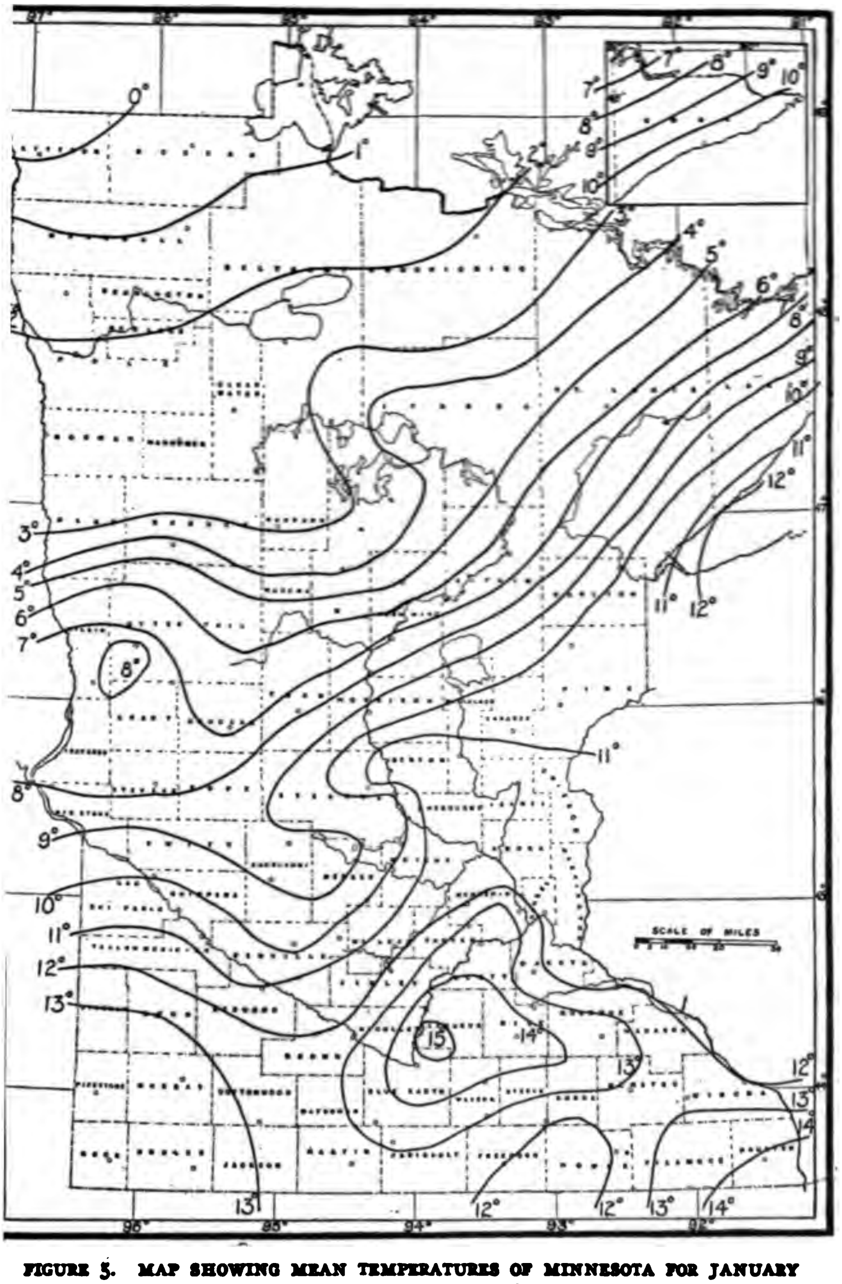


FIGURE 5. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JANUARY (DEGREES FAHRENHEIT)

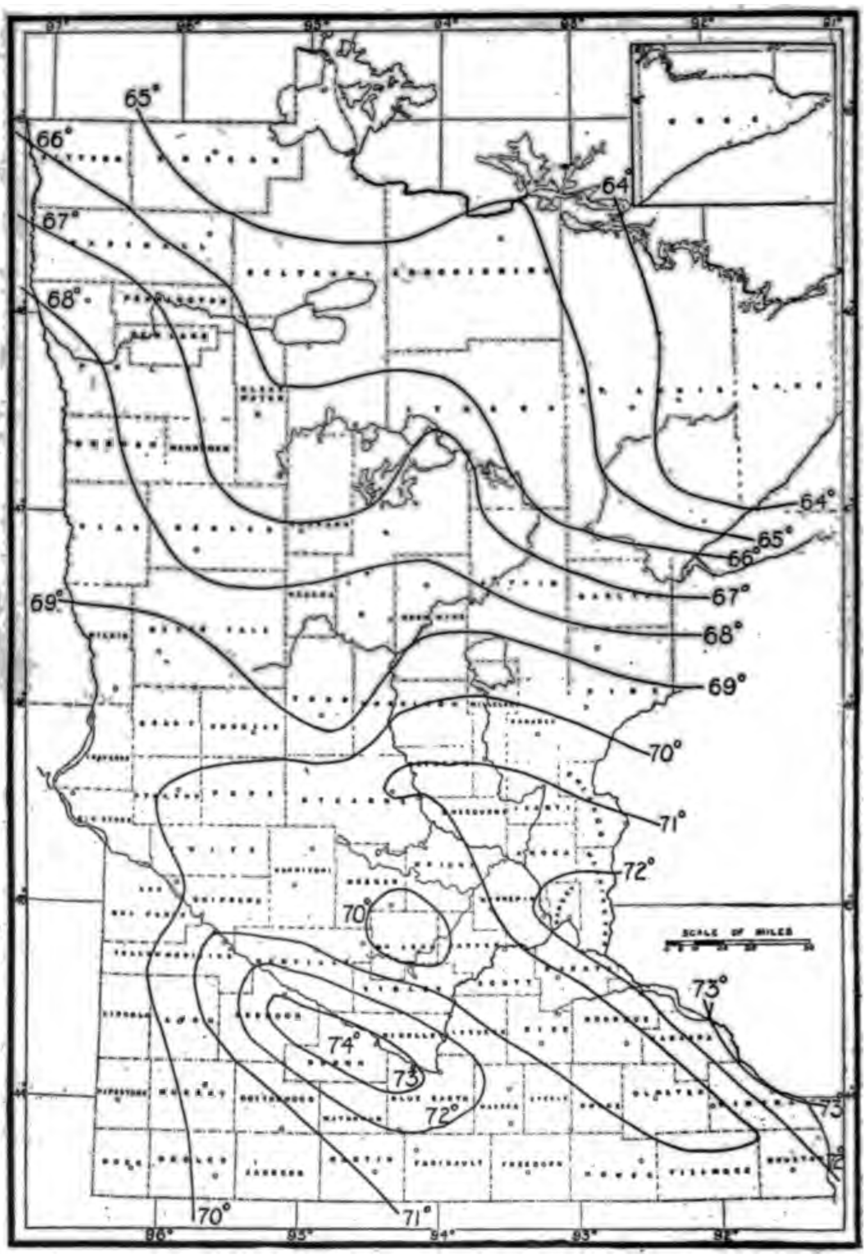


FIGURE 6. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

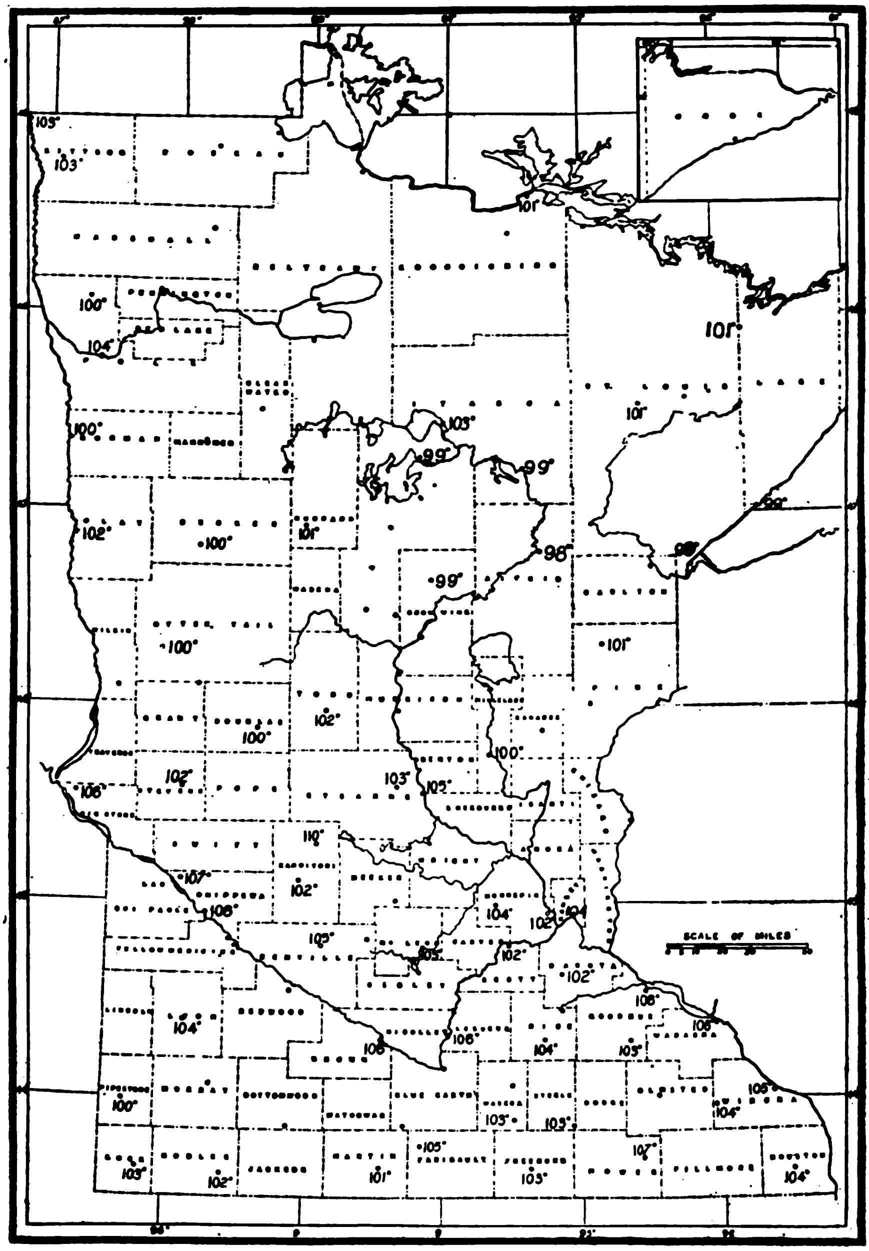


FIGURE 7. MAP SHOWING HIGHEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

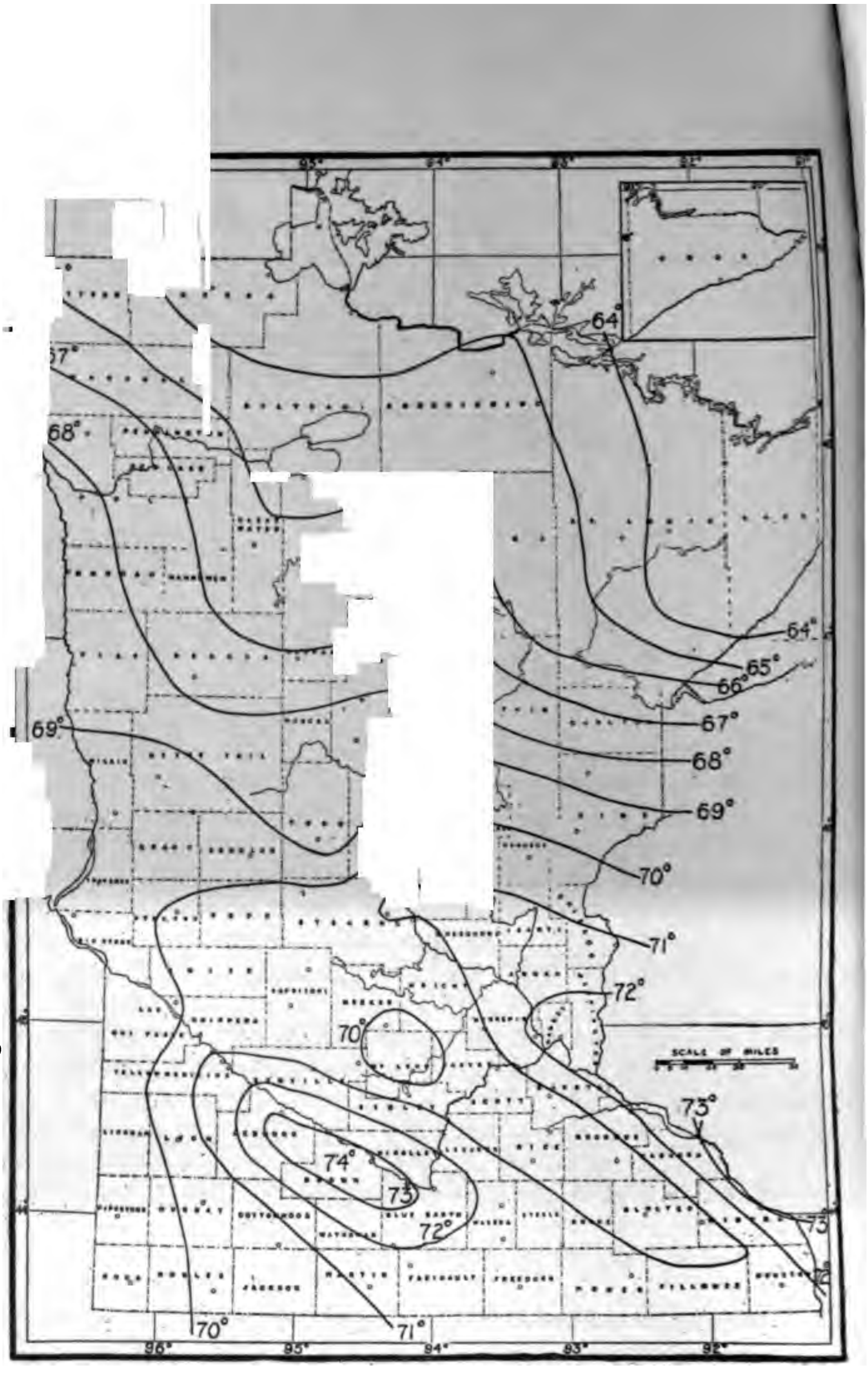


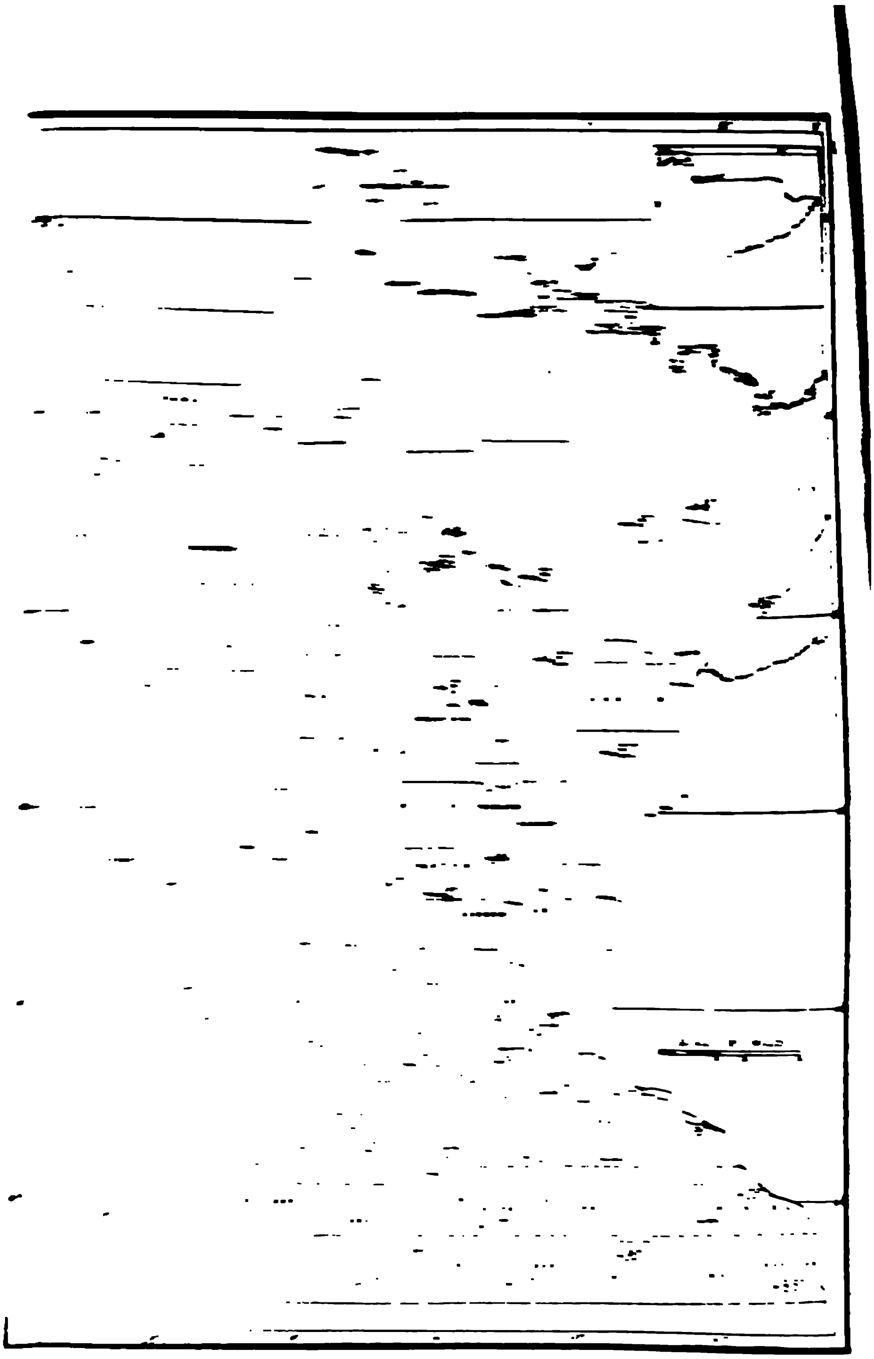
FIGURE 6. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

sippi River, and in the country immediately bordering on Lake Superior. Temperatures of —40° have occurred in nearly all northern and central counties and in a few southern counties, but these great extremes do not occur frequently.

Table II. Seasonal Temperatures for Minnesota (Degrees Fahrenheit)

Year	Winter mean	Spring mean	Summer mean	Fall mean	April to Sept. inclusive (crop-growing season)
1895	....	....	....	....	61.4
1896	16.2	42.3	68.1	38.2	60.7
1897	14.3	39.9	66.1	47.3	60.4
1898	15.7	43.1	67.9	43.4	60.6
1899	8.8	37.9	68.2	48.3	60.0
1900	13.8	44.3	70.0	46.2	62.9
1901	13.9	44.1	70.0	45.1	62.0
1902	14.8	44.5	65.4	45.2	58.5
1903	11.5	42.9	64.4	43.0	57.9
1904	5.5	40.0	64.7	47.2	57.6
1905	10.4	42.8	66.4	46.2	59.3
1906	17.1	40.7	66.9	46.6	60.9
1907	11.5	36.3	65.9	44.3	55.6
1908	18.5	41.8	65.8	48.3	60.1
1909	13.9	38.4	68.4	45.7	58.8
1910	9.8	47.1	68.1	44.8	60.4
1911	12.2	45.1	67.3	40.1	60.2
1912	7.8	40.4	65.0	46.2	58.9
1913	11.9	39.8	68.0	46.1	60.3
1914	15.3	41.8	67.7	48.5	60.3
Mean	12.8	41.7	67.0	45.3	59.8

Frosts.—Although frosts have occurred in some portions of the state every month of the year, damaging temperatures are not to be expected during June, July, and August, and they are comparatively rare in the last half of May and the first half of September. Records of ten or more years are available from a large number of places in the state, of which charts have been constructed showing the average date of the last killing frost in spring and the first one in autumn. Using these dates as boundaries, we can mark the average beginning and ending of crop growth and determine the average length of the growing season. All of this information is graphically shown in Figures 9, 10, and 11. By reference to Figure 11 the influence of Lake Superior in lengthening the crop-growing season in its vicinity may be seen; while in the same latitude in the highlands of Hubbard, Becker, eastern Mahnomen, and Clearwater counties the season is twenty to thirty days shorter. The longest season, 160 days, obtains along the Mississippi River from Hennepin County to the southeastern corner of the state, and the shortest, 100 days or less, is in the region of the Mesabi and Vermilion Iron ranges.



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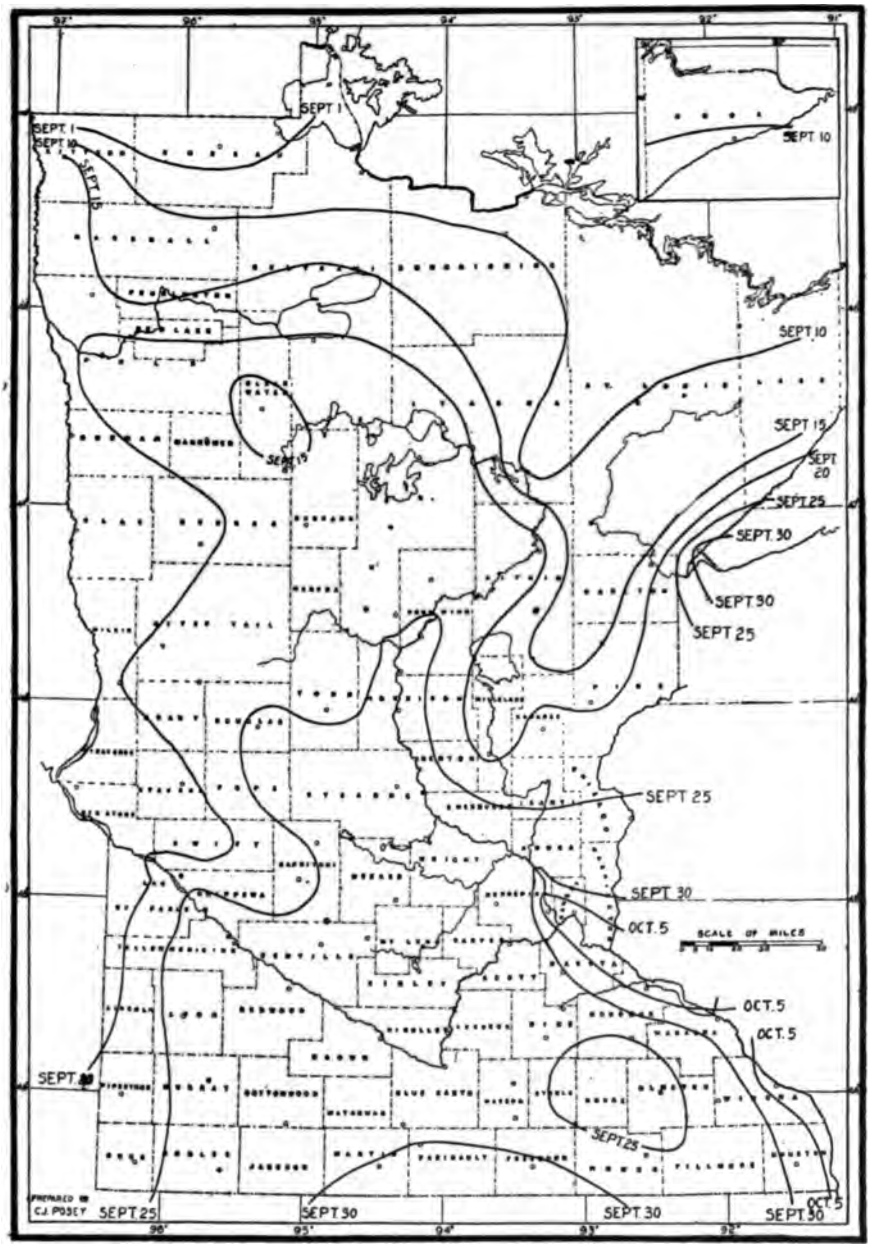

FIGURE 10. MAP SHOWING AVERAGE DATE OF FIRST KILLING FROST IN AUTUMN IN MINNESOTA

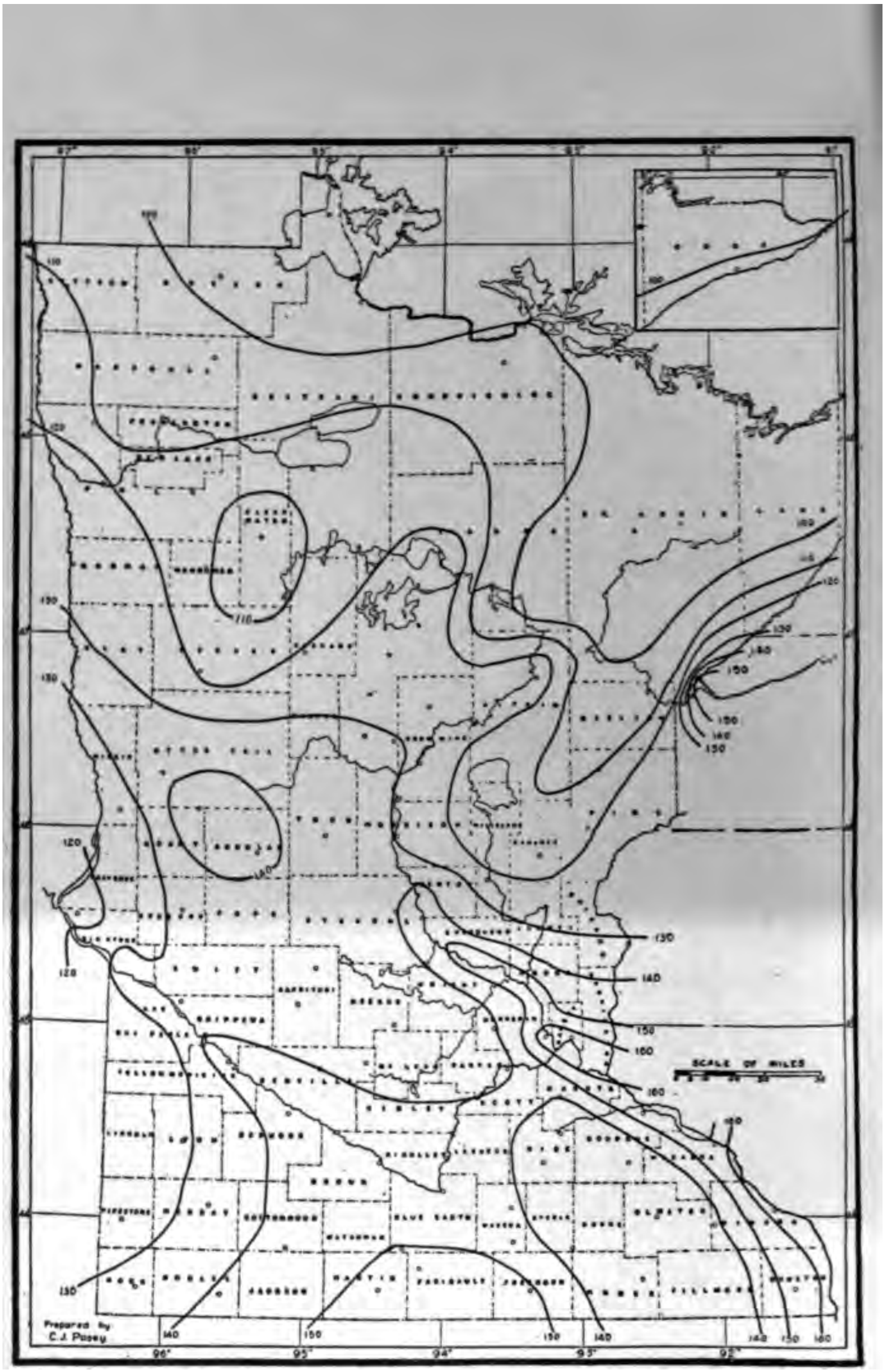

FIGURE II. MAP SHOWING NUMBER OF DAYS OF THE AVERAGE CROP-GROWING SEASON IN MINNESOTA

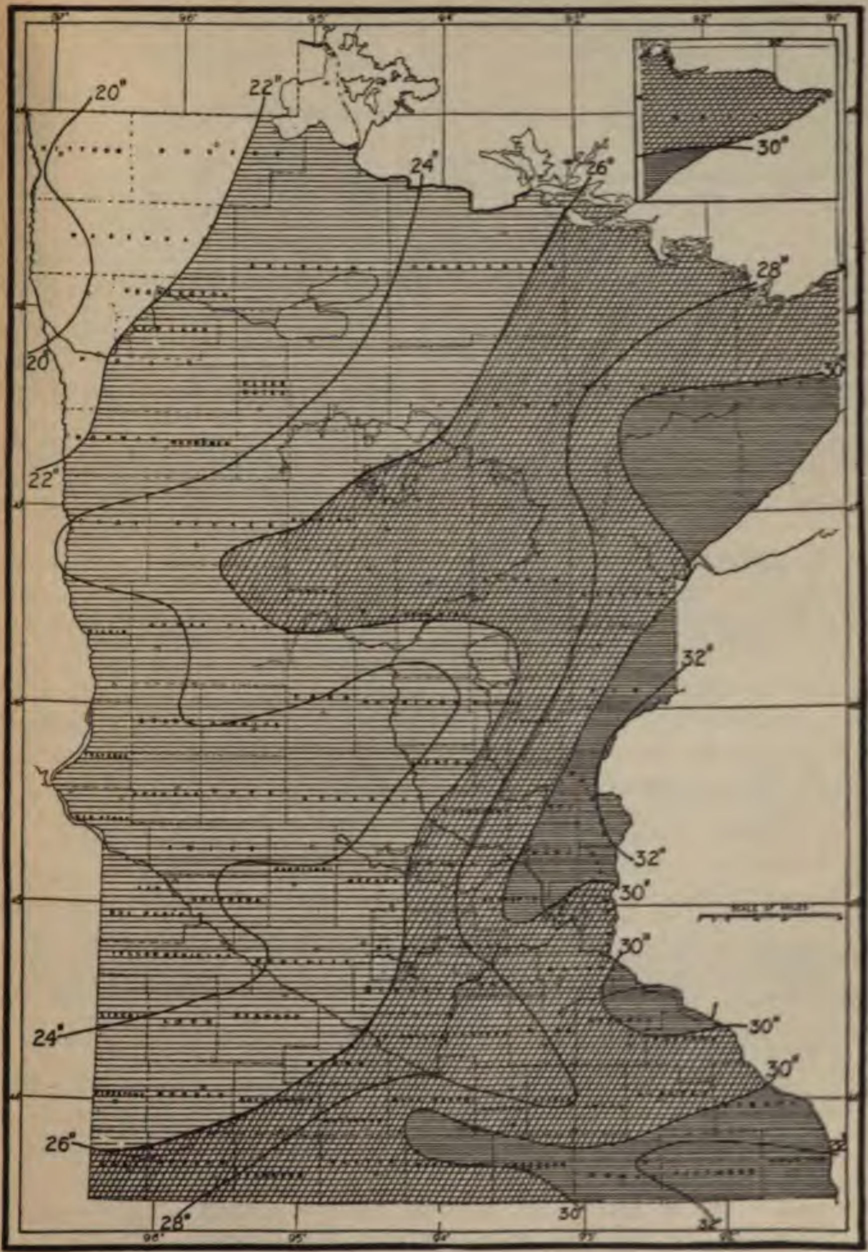

FIGURE 12. MAP SHOWING THE AVERAGE ANNUAL PRECIPITATION FOR MINNESOTA

Table III. Average Monthly and Annual Precipitation for Minnesota (in Inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Total April to Sept. incl.
1895	....	....	....	1.68	3.30	4.37	3.25	2.27	3.93	0.25	1.22	0.28	.....	18.80
1896	0.76	0.39	1.97	5.91	5.02	4.07	1.88	2.28	2.49	2.95	2.69	0.61	32.04	21.65
1897	1.77	1.21	2.07	1.55	1.38	5.40	6.62	2.54	1.89	1.55	0.53	0.38	27.23	19.38
1898	0.16	1.02	1.21	1.64	3.26	3.93	2.94	3.22	1.52	3.83	1.02	0.18	24.21	16.51
1899	0.60	0.78	1.58	1.49	4.46	6.36	2.84	5.35	1.47	3.22	0.63	0.95	30.14	21.97
1900	0.48	0.56	1.30	1.47	0.90	1.71	5.48	6.44	6.55	3.85	0.62	0.51	29.79	22.55
1901	0.38	0.40	1.68	1.73	1.41	5.81	3.33	2.21	4.34	1.86	0.78	0.57	24.26	18.83
1902	0.44	0.67	0.92	1.67	5.10	3.32	4.76	4.35	2.23	1.93	1.57	1.79	29.46	21.43
1903	0.45	0.59	1.75	2.82	5.37	1.96	5.11	4.65	5.63	3.13	0.35	0.84	32.85	25.54
1904	0.39	0.62	1.51	1.72	2.43	4.26	3.96	2.77	3.14	3.50	0.14	0.82	29.65	18.28
1905	0.65	0.55	1.21	1.46	5.54	6.41	4.12	4.36	3.45	2.53	2.64	0.15	33.10	25.34
1906	1.15	0.27	1.20	1.72	5.58	4.55	2.93	4.66	3.73	2.28	1.82	0.91	31.66	23.17
1907	1.17	0.58	0.94	1.01	2.14	4.31	3.57	4.11	3.48	1.31	0.57	0.57	24.03	18.62
1908	0.31	1.11	1.47	2.55	6.31	6.35	3.21	2.07	2.41	1.91	1.18	0.79	29.49	22.90
1909	1.32	1.31	0.54	1.89	3.36	3.53	3.84	5.54	3.16	1.56	2.68	1.54	29.27	20.32
1910	0.83	0.45	0.27	1.54	1.58	1.39	1.94	2.35	2.45	0.97	0.52	0.44	14.73	11.25
1911	0.81	0.88	0.63	1.88	3.48	3.79	3.61	4.27	3.35	3.93	1.12	1.35	29.10	20.38
1912	0.40	0.21	0.45	2.04	4.13	1.66	4.30	3.97	3.03	0.97	0.36	0.93	22.45	19.13
1913	0.33	0.44	1.27	1.87	3.53	3.08	5.56	2.79	3.33	2.58	0.66	0.05	25.49	20.16
1914	0.81	0.44	1.12	2.41	2.89	8.34	2.48	3.97	3.08	2.00	0.38	0.44	28.06	23.77
Mean	0.70	0.66	1.22	2.00	3.56	4.18	3.79	3.66	3.23	2.31	1.07	0.71	27.74	20.33

Precipitation.—The annual average precipitation of the state as a whole for a period of nineteen years, 1896 to 1914 inclusive, is 27.74 inches, and for the crop season, April to September inclusive, for twenty years, 1895 to 1914, is 20.33 inches. The monthly, seasonal, and annual averages for this period are shown in Table III. The year with the greatest annual rainfall was 1905, when the total was 33.10 inches. The driest year was 1910 with 14.73 inches. In that year the rainfall during the crop-growing season was 11.25 inches.

Table IV. Average Monthly and Annual Precipitation by Drainage Districts

Watersheds	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake Superior..	0.88	0.88	1.41	2.05	3.50	4.19	4.21	3.73	4.18	2.80	1.45	1.13	30.40
Rainy River....	0.94	0.94	1.42	1.96	3.10	4.04	3.76	3.32	2.98	2.08	1.46	0.98	26.98
Red River.....	0.55	0.56	0.98	1.84	2.85	3.83	3.34	3.12	2.32	1.55	0.72	0.56	22.22
Mississippi (above St. Croix)....	0.73	0.70	1.23	2.16	3.42	4.13	3.61	3.57	3.00	2.29	1.05	0.73	26.63
St. Croix and Mississippi (below St. Croix)....	0.92	0.95	1.49	2.37	4.01	4.46	3.72	3.69	3.72	2.73	1.36	1.13	30.57
Minnesota River	0.79	0.73	1.19	2.30	3.52	4.18	3.34	3.44	2.63	2.11	1.02	0.79	26.04
Big Sioux and Des Moines Rivers	0.50	0.54	1.13	2.09	4.00	4.39	3.49	3.58	2.79	2.07	0.94	0.63	26.15
State.......	0.76	0.75	1.25	2.18	3.53	4.19	3.55	3.50	3.02	2.24	1.09	0.84	26.90

June is the wettest month with an average rainfall of 4.18 inches, and July is next with 3.79 inches. The lowest monthly rainfall is that of February with an average of 0.66 inch. The greatest rainfall in one month for the state as a whole was 8.34 inches in June, 1914. The lowest rainfall for any month was .05 inch in December, 1913.

which permit drainage from its inner border to pass through it into the Sioux River system. The altitude of the highest points on the moraine is nearly 2,000 feet, and there are several square miles standing above 1,900 feet. The bordering till plains on each side of the moraine are also very elevated, much of their area in this county being above 1,800 feet. Glacial drainage lines led from this moraine southwestward into South Dakota to the Big Sioux valley.

The northeast half of Lincoln County is largely morainic, there being only narrow till plains between conspicuous ridges. These ridges are arranged one below another on the slope of the Coteau, the altitude of the outer ones being 1,700 to 1,800 feet, and of the inner 1,400 feet or less.

The strong moraines of this county include much loose-textured cobbly and bowldery drift, with a stony loam soil, but there are large sections with clayey till and only a moderate number of stones. The till plains have a pebbly clay loam soil.

Percentages of Classes of Land in Lincoln County

	Square miles	Per cent
Morainic drift with stony loam soil	75	14.02
Clayey moraine, pebbly clay loam	130	24.30
Till plains with stony loam soil	30	5.59
Till plains with black clay loam soil	268	50.10
Outwash plains and sandy glacial drainage	12	2.24
Marshes and bogs	20	3.74
	535	99.99

Farm and Crop Data for Lincoln County from Census of 1910

Rural population 7,429 or 14 per square mile	
Per cent of land area in farms	89.4
Per cent of farm land improved	81.4
Average acres per farm	234.8
Average improved acres per farm	191.2
Value of all farm property	$15,729,215
Per cent of increase 1900 to 1910	104.9
Value of all crops in 1909	$1,830,475
Cereals (oats, barley, wheat, corn, rye)	$1,333,054
Other grains and seeds	$194,437
Hay and forage*	$260,027
Vegetables	$37,860
Fruits and nuts	$2,967
All other crops	$2,130

* Tame grass, 32,203 tons; wild grass, 28,538 tons.

PIPESTONE COUNTY

Pipestone County is situated on the west border of southwestern Minnesota with Pipestone as the county seat. The drainage is nearly all southwestward to the Big Sioux River, but the northeast corner drains northeastward to the Minnesota River. The crest of the Coteau des Prairies forms the divide and is followed by the highest moraine of the

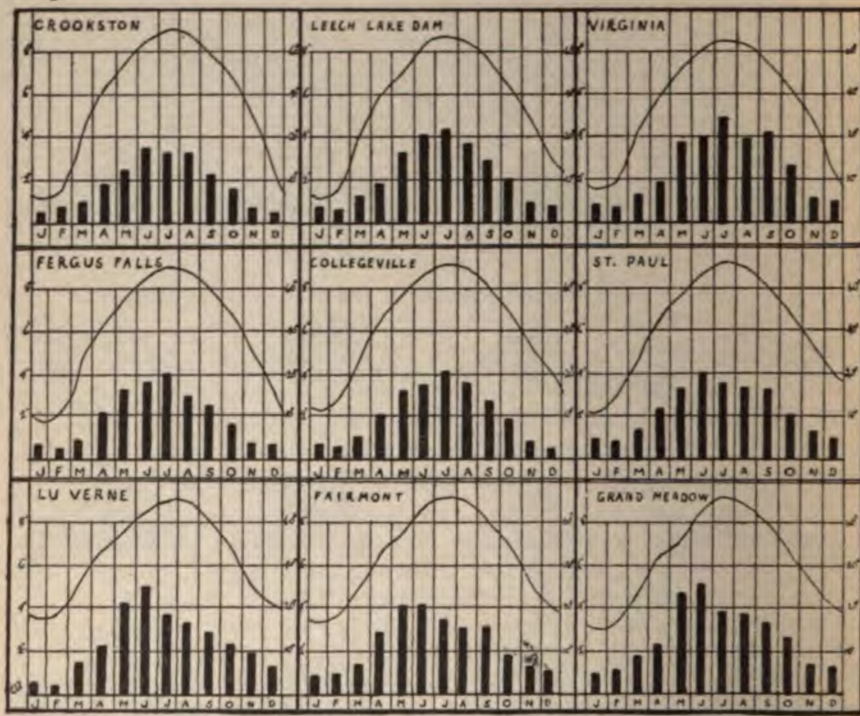

FIGURE 14. DIAGRAM SHOWING MEAN MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURE AT SEVERAL STATIONS IN MINNESOTA. MONTHS ARE INDICATED BY THEIR FIRST LETTERS. THE GREATEST RAINFALL IS IN THE GROWING SEASON

Farm and Crop Data for Pipestone County (Continued)

Average acres per farm	254.0
Average improved acres per farm	237.4
Value of all farm property	$17,022,735
Per cent of increase 1900 to 1910	133.8
Value of all crops in 1909	$1,762,497
Cereals (oats, barley, corn, wheat, rye)	$1,397,123
Other grains and seeds	$65,914
Hay and forage*	$238,190
Vegetables	$58,787
Fruits and nuts	$2,024
All other crops	$459

* Tame grass, 39,410 tons; wild grass, 10,585 tons.

MURRAY COUNTY

Murray County, of which Slayton is the county seat, is located in the southwest part of the state, and has a land area of 704 square miles, with about 16 square miles additional in small lakes. The drainage of this county is in three different systems, the northeast part being drained northeastward to the Minnesota, the central and southeast parts southeastward by the Des Moines River, and the southwest part southwestward to the Big Sioux River.

The crest of the Coteau des Prairies runs through the western part of the county, and is followed by a strong moraine. Parts of the moraine rise above 1,900 feet, and much of it above 1,800 feet, but there is a gap in it at Chandler which is only 1,650 feet. A few square miles on the east side of this moraine drain westward through this gap toward the Big Sioux River. The drainage of the eastern slope is chiefly to the Des Moines River. In the southwest part of the county the moraine just referred to becomes double and continues so southeastward into Iowa. The inner member makes a sharp loop northeastward to Hadley before taking this southeastward course. In this loop it has much gravelly drift, but elsewhere is composed chiefly of clayey though rather stony till. The outer member and the united moraine is largely of stony character with a few gravel knolls and a stony loam soil. There is a narrow strip of outwash gravel on part of the outer border. There was also a strong glacial drainage down Chanarambie Creek from Chandler.

Outside the moraine just outlined a thin veneer of young Wisconsin drift is spread over the eroded surface of the old gray drift. It only partly fills the interglacial valleys cut in that drift. The soil in this area is a wind drifted silt loam, coating the till to a depth of only a few inches. The subsoil is a pebbly clay loam with fewer stones than on the moraine.

East of the moraine that forms the crest of the Coteau is a broad till plain covering more than half of the county, and having a rich black clay loam soil. Northeast of this plain is a strong morainic system coming in from the northwest and sweeping around the south and east side of

The geographic distribution of annual and monthly precipitation is graphically shown in Figures 12 to 14, and for the stations having ten or more years of record in Table V. Table IV shows the monthly and annual distribution in the various watersheds. From these illustrations it may be seen that the precipitation is about one-fourth to one-third greater along the eastern boundary of the state than along the western boundary.

Table V. Average Annual Precipitation in Minnesota by Stations

Stations	County	Length of record	Average annual precip.	Station	County	Length of record	Average annual precip.
		Yrs.	Inches			Yrs.	Inches
Albert Lea	Freeborn	21	29.90	Montevideo	Chippewa	22	23.50
Alexandria	Douglas	25	23.74	Moorhead	Clay	31	24.92
Angus	Polk	10	19.00	Morris	Stevens	27	23.23
Ashby	Grant	14	24.47	New London	Kandiyohi	18	23.62
Beardsley	Bigstone	16	23.79	New Richland	Waseca	10	29.91
Bird Island	Renville	22	24.23	New Ulm	Brown	32	27.74
Blooming Prairie	Steele	13	27.45	Northfield	Rice	12	29.92
Caledonia	Houston	19	33.70	Osceola, Wis.	Polk	21	32.13
Collegeville	Stearns	19	22.76	Park Rapids	Hubbard	22	25.71
Crookston	Polk	22	22.41	Pembina, N. D.	Pembina	14	19.79
Detroit	Becker	16	25.96	Pine River Dam	Crow Wing	25	27.52
Duluth	St. Louis	41	29.93	Pipestone	Pipestone	12	24.18
Fairmont (near)	Martin	25	28.20	Pokegama Falls	Itasca	25	27.62
Faribault	Rice	14	28.00	Red Wing	Goodhue	16	31.71
Farmington	Dakota	24	29.29	Redwood Falls	Redwood	13	24.65
Fergus Falls	Otter Tail	24	23.24	Reeds Landing	Wabasha	16	29.31
Flandreau, S. D.	Moody	22	24.57	St. Charles	Winona	21	30.68
Fort Ripley	Crow Wing	43	25.25	St. Cloud	Sherburne	19	27.68
Glencoe	McLeod	15	26.64	St. Paul	Ramsey	41	28.68
Grand Meadow	Mower	24	32.59	St. Peter	Nicollet	18	27.89
Grantsburg, Wis.	Burnett	21	33.06	Sandy Lake Dam	Aitkin	19	26.47
Hallock	Kittson	13	21.37	Shakopee	Scott	15	28.85
Halstad (Ada)	Norman	16	21.27	Tonka	Hennepin	13	30.54
International Falls	Koochiching	10	25.75	Tower (Ely)	St. Louis	10	28.17
La Crosse, Wis.	La Crosse	40	31.17	Two Harbors	Lake	18	30.56
Leech Lake Dam	Cass	24	27.00	University, N. D.	Grand Forks	20	20.47
Long Prairie	Todd	20	25.17	Virginia (Mt. Iron)	St. Louis	18	30.74
Luverne	Rock	15	27.60	Wabasha	Wabasha	17	30.54
Lynd	Lyon	19	25.43	Wahpeton, N. D.	Richland	20	23.67
Mankato	Blue Earth	14	27.50	Willmar	Kandiyohi	10	25.54
Mapleplain	Hennepin	17	31.11	Willow River	Pine	10	29.98
Milaca	Mille Lacs	13	27.27	Winnebago	Faribault	14	30.58
Milan	Chippewa	18	24.49	Winnibigoshish	Itasca	25	25.66
Milbank, S. D.	Grant	21	22.69	Winona	Winona	16	29.63
Minneapolis	Hennepin	21	29.31	Worthington	Nobles	17	28.24

Figure 14 makes an interesting comparison of monthly and annual values of both temperature and rainfall at certain selected representative stations.

Snowfall.—The snowfall averages from 24 to 54 inches. It is lightest in the southwest portion of the state and heaviest on the Mesabi Iron Range. The monthly and annual averages are shown in Table VI, arranged according to sections and drainage districts.

Winds.—The prevailing winds are from the northwest over most of the state. The monthly and annual prevailing directions are shown for a large group of stations in Table VII. The average hourly wind velocity is shown for six regular Weather Bureau stations and three special stations in Table VIII.

Table VI. Average Snowfall

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Yrs.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake of the Woods Group—														
Tower	9	9.0	8.6	10.9	4.2	0.6	0	0	0	0.2	0.4	8.4	8.2	50.5
Red River Valley Group—														
St. Vincent-Pembina	14	8.4	5.1	6.9	5.2	0.7	0	0	0	0.1	0.7	5.7	6.4	39.2
Crookston	14	6.3	6.7	8.8	3.2	2.0	0	0	0	T.	0.4	4.5	5.7	35.8
Moorhead	17	7.6	6.7	8.9	4.9	0.3	0	0	0	0.1	1.0	6.9	6.8	43.7
Upper Mississippi River Valley Group—														
Park Rapids	14	9.0	6.5	9.1	5.4	0.9	0	0	0	0.2	1.4	7.4	6.3	46.2
Lake Winnibigoshish	14	8.6	6.5	9.9	3.3	0.8	0	0	0	T.	1.0	7.8	7.8	45.7
Sandy Lake Dam	14	9.0	9.5	10.6	3.6	0.7	0	0	0	0.2	1.1	7.4	7.4	49.4
Lake Superior Group—														
Mt. Iron	13	9.9	7.8	11.2	3.9	1.1	0	0	0	0.1	0.8	8.1	11.6	54.4
Duluth	25	10.3	9.1	11.1	4.0	1.0	0	0	0	0.1	0.3	8.2	8.7	52.8
Lower Mississippi River Valley Group—														
La Crosse, Wis.	15	8.4	8.7	6.6	1.4	T.	0	0	0	T.	0.1	3.9	8.9	37.1
Grand Meadow	14	8.0	9.8	9.9	3.1	0.4	0	0	0	T.	0.3	5.3	9.3	46.1
St. Charles	9	7.7	9.4	9.5	2.4	0.2	0	0	0	0	0.1	4.3	9.3	42.9
Red Wing	8	8.0	5.6	4.4	1.8	0.2	0	0	0	T.	0.3	1.5	7.1	28.9
St. Paul	24	7.7	6.2	8.8	3.6	0.2	0	0	0	T.	0.2	4.7	5.7	37.1
Lower Minnesota River Valley Group—														
Shakopee	14	7.7	8.1	7.8	1.9	T.	0	0	0	T.	0.4	3.0	4.6	33.5
St. Peter	13	5.5	6.1	7.1	0.7	T.	0	0	0	0	0.4	1.4	4.0	25.2
Winnebago	10	6.5	7.5	6.3	1.0	T	0	0	0	T.	0.3	2.3	6.5	30.4
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8.3	8.6	9.5	4.0	0.2	0	0	0	T.	0.3	4.5	6.4	42.4
Collegeville	14	6.7	5.6	8.5	1.8	0.4	0	0	0	T.	0.3	3.5	5.0	31.8
Pine River Dam	14	9.1	8.4	9.5	2.8	2.8	0	0	0	0.1	0.6	5.9	6.8	44.0
Osceola, Wis.	11	9.1	8.4	11.7	2.8	T.	0	0	0	T.	0.1	5.5	6.8	44.4
Grantsburg, Wis.	11	9.2	9.0	12.2	4.2	0.1	0	0	0	0	0.1	8.5	8.9	52.2
Upper Minnesota River Valley Group—														
New Ulm	14	8.9	7.5	9.5	1.7	0.2	0	0	0	T.	0.3	3.5	4.4	36.0
Bird Island	14	4.7	5.8	6.0	1.5	0.4	0	0	0	T.	0.5	3.5	3.4	25.8
Milan	14	7.5	8.1	11.2	1.6	0.5	0	0	0	T.	0.6	4.1	6.1	39.7
Minnesota River Watershed Group—														
New London	14	4.6	4.2	7.0	1.7	0.1	0	0	0	0	0.3	2.7	3.4	24.0
Long Prairie	14	5.7	5.5	7.4	2.4	0.4	0	0	0	T.	0.2	3.3	4.4	29.3
Morris	14	5.2	5.4	7.8	2.1	0.5	0	0	0	0	0.6	3.2	4.4	29.2
Fergus Falls	13	6.2	5.7	7.6	2.8	0.4	0	0	0	T.	1.0	5.7	5.8	35.2
Southwestern Group—														
Fairmont	13	5.0	10.0	8.8	1.9	0.1	0	0	0	T.	0.2	3.9	5.3	35.2
Worthington	13	4.1	7.2	7.6	1.2	T.	0	0	0	0	0.3	2.7	3.6	26.7
Lynd	14	6.3	5.1	7.4	2.8	0.5	0	0	0	T.	1.2	2.8	5.3	31.4
Gary, S. D.	11	4.4	6.6	12.4	4.5	0.2	0	0	0	T.	1.2	4.2	4.1	37.6

Relative humidity.—The average annual humidity for the state is 83 per cent at 7 a.m. and 72 per cent at 7 p.m. Table IX gives the monthly and annual data.

Number of rainy days.—In Table X the number of rainy days during each month and the year is given for thirty-three stations well distributed over the state. The smallest number is 64 at Lynd, Lyon County, and the largest 132 days at Duluth.

Sunshine.—The sunshine is abundant, averaging from 43 to 53 per cent of the highest amount possible. The daylight hours are materially longer during the crop-growing season in the northern portion of the state than in the southern. The greatest percentage of sunshine is in the southwestern portion and the least in the northeastern part.

Table VII. Prevailing Wind Direction

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Year
Lake of the Woods Group—														
Tower	9	nw.	w.	nw.	w.	w.	w.	w.	w.	w.	w.	w.	nw.	w.
Red River Valley Group—														
St. Vincent-Pembina	23	nw.	nw.	nw.	nw.	nw.	se.	s.	se.	nw.	nw.	nw.	nw.	nw.
Crookston	14	s.	nw.	s.	n.	nw.	s.	sw.	se.	nw.	s.	s.	nw.	s.
Moorhead	28	nw.	nw.	nw.	n.	n.	se.	s.	se.	se.	se.	nw.	nw.	s.
Upper Mississippi River Valley Group—														
Park Rapids	16	nw.	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lake Winnibigoshish	16	nw.	nw.	w.	nw.	nw.	w.	w.	w.	w.	nw.	nw.	nw.	nw.
Sandy Lake Dam	14	nw.	nw.	nw.	se.	e.	e.	nw.	nw.	s.	nw.	nw.	nw.	nw.
Lake Superior Group—														
Mt. Iron	14	nw.	n.	n.	n.	n.	s.	s.	n.	s.	s.	nw.	nw.	n.
Duluth	38	sw.	nw.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	sw.	sw.	ne.
Lower Mississippi River Valley Group—														
La Crosse, Wis.	36	s.	s.	n.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Grand Meadow	15	nw.	nw.	nw.	nw.	nw.	se.	s.	s.	s.	sw.	nw.	nw.	nw.
St. Charles	13	nw.	nw.	se.	se.	nw.	se.	se.	nw.	s.	se.	nw.	nw.	nw.
Red Wing	12	nw.	nw.	nw.	se.	e.	se.	sw.	w.	e.	w.	nw.	nw.	nw.
St. Paul	38	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Lower Minnesota River Valley Group—														
Shakopee	14	nw.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
St. Peter	13	nw.	nw.	nw.	nw.	nw.	nw.	se.	nw.	s.	nw.	nw.	nw.	nw.
Winnebago	9	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	nw.
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	nw.	nw.	nw.	nw.	ne.	s.	s.	s.	s.	s.	nw.	nw.	nw.
Collegeville	14	nw.	nw.	nw.	s.	nw.	sw.	s.	nw.	s.	nw.	nw.	nw.	nw.
Pine River Dam	16	nw.	nw.	nw.	nw.	nw.	w.	w.	nw.	nw.	nw.	nw.	nw.	nw.
Osceola, Wis.	11	s.	s.	n.	n.	s.	s.	s.	s.	s.	n.	n.	s.	s.
Grantsburg, Wis.	11	nw.	nw.	sw.	se.	ne.	sw.	sw.	sw.	sw.	nw.	nw.	nw.	nw.
Upper Minnesota River Valley Group—														
New Ulm	14	nw.	nw.	s.	s.	s.	s.	s.	s.	nw.	nw.	nw.	nw.	nw.
Bird Island	16	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Milan	14	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Minnesota River Watershed Group—														
New London	14	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Long Prairie	14	nw.	nw.	nw.	se.	se.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.
Morris	17	nw.	nw.	s.	s.	s.	s.	s.	s.	s.	s.	n.	s.	s.
Fergus Falls	13	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Southwestern Group—														
Fairmont	15	nw.	nw.	nw.	nw.	nw.	s.	s.	nw.	s.	nw.	nw.	nw.	nw.
Worthington	13	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lynd	14	nw.	nw.	nw.	nw.	se.	nw.	sw.	nw.	nw.	sw.	nw.	nw.	nw.
Gary, S. D.	11	nw.	nw.	nw.	sw.	se.	se.	se.	s.	ne.	sw.	nw.	nw.	nw.

Table VIII. Average Hourly Wind Velocity in Miles

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	5	14.3	14.2	15.0	15.1	15.2	11.6	11.3	12.0	12.7	13.9	14.1	14.2	13.6
Moorhead	19	10.3	10.5	11.3	12.0	10.7	10.0	8.3	8.4	10.4	10.4	10.1	10.0	10.2
St. Vinc'nt-Pembina	15	7.7	9.4	10.0	10.7	10.9	8.7	7.5	7.5	9.1	9.3	9.5	8.9	9.2
Two Harbors	6	9.0	8.2	9.7	9.4	7.6	7.4	7.3	7.2	8.0	8.3	8.7	8.9	8.3
La Crosse, Wis.	36	7.1	7.5	8.0	8.5	7.5	6.7	6.0	5.8	6.9	7.5	7.5	7.2	7.2
St. Paul	36	7.8	8.3	8.8	9.3	8.7	7.7	7.1	7.1	8.0	8.5	8.1	7.8	8.1
Minneapolis	18	11.5	11.6	12.3	12.8	12.1	10.3	9.9	9.9	11.6	11.7	11.0	11.2	11.3
Faribault	7	9.4	9.1	9.4	11.0	9.0	7.3	5.9	6.4	7.8	8.8	9.0	9.1	8.5
Collegeville	11	9.5	9.6	11.0	12.2	11.1	10.0	9.4	9.4	10.9	9.5	9.9	9.9	10.2

CHAPTER III

AGRICULTURAL CONDITIONS AND LAND CLASSIFICATION IN THE SOUTH HALF OF MINNESOTA

GENERAL STATEMENT

The area embraced in this report extends from the median line of the state, about latitude 46° 25′, southward to the Iowa state line. It embraces about 40,000 square miles, including lakes. It is largely tributary to the Mississippi River, there being only about 3,550 square miles, or less than 9 per cent drained by other streams. Of this, 60 to 70 square miles in the northeast corner of Pine County drains northeastward to Lake Superior; about 1,840 square miles is tributary to Red River of the North; and 1,650 square miles is drained southwestward to the Missouri River. In the Mississippi drainage about 15,000 square miles falls within the Minnesota River watershed, and over 21,000 square miles in the main stream and other tributaries of the Mississippi. Part of this is drained by the Des Moines, Cedar, and upper Iowa rivers across Iowa to the Mississippi, while the St. Croix River flows along the border of the state to its junction with the Mississippi.

The altitude of the south half of the state has a range of about 1,350 feet, the lowest being 615 feet, at the southeast corner of the state, and the highest 1,950 to 1,975 feet, in high points on the Coteau des Prairies in the southwest part. The average altitude is not far from 1,200 feet. Only a small part aside from river valleys is below 1,000 feet, and only a small part above 1,500 feet.

The average rainfall ranges from less than 24 inches, in the western part, to 30 to 32 inches in the eastern (Figure 12). The rainfall is largely in the crop-growing season, and is usually sufficient for the proper maturing of all the crops.

As indicated in the discussion of the general features of the state, the topographic and agricultural conditions are quite varied. It may, therefore, be of advantage to outline briefly certain of the characteristics of each of the several classes of land, beginning with the driftless area, and taking up the several drifts and associated deposits in order of their age and the alluvial deposits of the present streams.

DRIFTLESS AREA

The portion of Minnesota falling within the driftless area of the upper Mississippi valley is confined to Houston County and the eastern part of Winona County. In this area the uplands have a residuary clay covering the rock to a depth of a few feet, above which there is a deposit

of wind borne silt-loam (loess) having a depth of 10 to 15 feet or more. This loess extends down on the gentle slopes from the crests of the divides between the streams, leaving only the steeper part of the slopes with rock exposed. This area is, therefore, rendered more productive by the presence of the deposit of loess which has buried the less productive residuary clays beneath it. The steep parts of the slopes which are difficult to till are utilized to a large degree for pasture.

LOESS-COVERED PRE-WISCONSIN GRAY DRIFT

Pebbly border.—For several miles back from the eastern limits of the old drift there are usually only scattered pebbles and occasional bowlders to mark the former extent of glaciation. The topography is indistinguishable from that of the driftless area, and the glaciation was usually so weak that the preglacial residuary clay is still present on the rock formation. A sheet of loess covers the pebbles to a depth of 10 to 15 feet or more, and it is this which gives the productiveness to the soil. A considerable part of Wabasha County, western Winona County, eastern Olmsted County, eastern Fillmore County, and western Houston County falls within the limits of this pebble and bowlder area. Rock bluffs are about as conspicuous as in the driftless area, but the valleys of tributaries of the Mississippi are narrower than on the lower courses of the streams in the driftless area proper.

Old gray till (Kansan).—The loess overlaps for a few miles the eastern edge of heavy deposits of an old calcareous till. This was leached to a depth of several feet before the deposition of the loess, and is usually oxidized to a yellowish brown color to a depth of 15 to 20 feet. When of greater thickness, it retains the original bluish gray color. Eastern Goodhue County, southwestern Wabasha County, western Olmsted County, northeastern Dodge County, and part of the western half of Fillmore County, have thick deposits of old drift beneath the loess. The loess, however, is so heavy a deposit as a rule that the crops are dependent upon it rather than upon the underlying drift. The amount of this drift is sufficient to reduce greatly the roughness of the surface.

There is an area of the old gray drift in the southwest corner of the state in Rock, Pipestone, and Nobles counties, of which about 170 square miles in the extreme southwest corner of the state, were covered by a deposit of loess to several feet in depth, or of sufficient thickness to entirely sustain the crops. This gives place on the north and east somewhat abruptly to a thin coating of wind drifted silt a few inches to 2 or 3 feet in depth which is not included in the area mapped as loess on the map of the surface formations of Minnesota. Much of the deposit is probably derived from the loess, but the silt is mixed to some extent with sand

grains and small pebbles from the underlying till. It appears to have been deposited by winds that were dragging the surface and transporting coarse and fine grains gathered from bare or exposed surfaces of loess or till, a process still in operation. The typical loess, on the other hand, is a very uniform deposit, such as might result from the settling of dust which had been held in the atmosphere. It is not always feasible to draw a definite line or boundary between the deposits, but the map sets forth the approximate extent of the typical loess.

The drift is sufficient in southwest Minnesota to fill the preglacial valleys, but some of the more prominent quartzite ridges stand above the general level of this drift filling. Parts of these ridges are entirely bare, but they seem likely to have formerly carried a coating of drift which has been removed by erosion, for the glaciated surfaces of the rocks frequently have the striae well preserved. This could hardly be the case if they had been exposed to weathering ever since the ice disappeared from this region. The depth of leaching in this old drift is much less than in southeastern Minnesota, being usually but 2 to 3 feet or even less. The difference seems attributable in part at least to the smaller rainfall and a lesser amount of downward penetration of water in southwestern Minnesota.

OLD GRAY DRIFT (KANSAN), WITH LITTLE OR NO LOESS COVER

Immediately west of the loess covered area in southeastern Minnesota is an old gray drift with little or no silt cover over it, which extends westward and passes under the young or Wisconsin gray drift of southern Minnesota. From the state line northward across Mower, Dodge, western Goodhue, eastern Rice, and southwestern Dakota counties, it is very largely composed of clayey till which has been leached of its lime to a depth of several feet, and oxidized to a depth of about 15 feet, below which it retains the original bluish gray color. It has been termed in the earlier reports of the Minnesota Geological Survey the old gray drift. A large part of it appears to be of Kansan age, and its surface was greatly eroded subsequent to the Kansan glaciation.

IOWAN DRIFT OVER KANSAN DRIFT

The southeast part of Minnesota and the northeast part of Iowa include an area which differs somewhat from Kansan drift areas farther south. The general depth of leaching is less than in those areas, and the surface of the drift is not so deeply reddened by oxidation. The valleys in this area are in some cases mere swales without definite bluffs, and as a rule they are shallower than in the Kansan drift areas to the south. There are knolls on the slopes and on the valley bottoms, which in some

SHERBURNE COUNTY

Sherburne County is situated east of the Mississippi River, in the south central part of Minnesota, with Elk River as the county seat. It has a land area of 448 square miles, to which should be added 15 to 20 square miles in lakes.

Elk River gathers nearly all the drainage of Sherburne County and parallels the Mississippi from the northwest to the southeast corner of the county, where it enters the Mississippi. The eastern part of the county drains into Rum River and thence to the Mississippi River at Anoka.

With the exception of the northern edge of the county, where there are a few square miles of clayey ground moraine of red drift, the Grantsburg lobe of the Keewatin ice field covered the entire county. Its morainic ridges and knolls have gray drift material with a large red drift admixture. The movement of the Keewatin ice was northeastward, and the drainage on its north side took a northeastward course along or near the ice border to the end of the lobe and thence down the St. Croix valley. Part of it was ponded, as indicated in the discussion of Mille Lacs and Kanabec counties, but there seems to have been a rather free current across northern Sherburne County which deposited sand and fine gravel rather than mud or silt.

Along the Mississippi and Elk rivers there is a long strip of gravelly outwash, with light sandy soil. To the east of this strip are large areas covered by fine dune sand, above which there rise a few sharp morainic knolls and ridges. There are gravel plains with light sandy soil also along St. Francis River in the north part of the county. A large area in the southeast part of the county comprises mainly moraines of sandy till with loamy soil.

The amount of wet land in Sherburne County is estimated to be 10,000 acres, and is largely in marshy bogs among sandy areas.

The variable character of the soil is set forth in the table below:

Percentages of Classes of Land in Sherburne County

	Square miles	Per cent
Sandy gray drift moraine; soil sandy and stony loam	42	9.38
Clayey gray drift; soil pebbly clay loam	15	3.34
Sandy gray drift till plain; soil sandy to stony loam	14	3.13
Clayey gray drift till plain; soil pebbly clay loam	6	1.34
Clayey red drift till plain; soil pebbly clay loam	12	2.68
Marshes and swamps	15	3.34
Outwash gravel and sand	180	40.18
Dune sand	164	36.60
	448	99.99

Farm and Crop Data for Dodge County from Census of 1910

Rural population 8,350 or 19 per square mile

Per cent of land area in farms	93.0
Per cent of farm land improved	86.5
Average acres per farm	165.0
Average improved acres per farm	142.8
Value of all farm property	$17,416,051
Per cent of increase 1900 to 1910	80.5
Value of all crops in 1909	$1,830,210
Cereals (barley, oats, corn, wheat, rye)	$1,175,703
Other grains and seeds	$173,979
Hay and forage*	$363,432
Vegetables	$56,298
Fruits and nuts	$15,799
All other crops	$44,999

* Tame grass, 62,826 tons; wild grass, 8,079 tons.

OLMSTED COUNTY

Olmsted County, of which Rochester is the county seat, is located in the southeast part of the state. The drainage of the eastern part of the county is eastward by Whitewater River; of the central and northwest parts northeastward by the Zumbro River; and of the southern part eastward by Root River to the Mississippi. The divides separating these three river systems rise in places slightly above 1,300 feet, and the greater part of the county is between 1,200 and 1,300 feet. The valleys are cut to a much lower level, and the Zumbro River falls below 900 feet at the north edge of the county. The principal streams are bordered by prominent rock bluffs, but the uplands are gently undulating. The cover of drift is generally thin. There are many sink holes in the limestone in the southern part of the county.

The drift is all of pre-Wisconsin age and has suffered considerable leaching and weathering. It is generally a stiff clayey till which becomes calcareous below the leached part at a depth of 4 to 6 feet.

Large gravel knolls occur in the line of an old valley in southern Oronoko Township, and there are smaller ones here and there in the central and western part of the county, and very rarely in the eastern part. Most of the drift in the valleys and lowlands is loose-textured, both in the low bottoms and on terraces.

Loess deposits form a coating widely over the till in the northeast quarter of the county and in several of the southern townships, but in the remainder of the county it is in isolated strips. A belt of land several miles wide running eastward from Rochester into Winona County is free from loess,—the land both to the north and south of it being widely loess covered.

being only 161 square miles. There is an additional 13.45 square miles in the lakes and streams within or on the borders of the county.

The Mississippi River is at and near the southern edge of the county in a deep rock-bound valley along part of which broad rock shelves are exposed by erosion and the removal of drift deposits by glacial drainage which made the valley. A small preglacial valley which comes into the present Mississippi near the Union Depot at St. Paul is only partly filled with drift, and furnishes a line of entry for several of the railways coming into the city from the east and north.

There are a few square miles of gray drift in the southwest part of the county, but the remainder of the county is largely red drift moraine with outwash gravel plains among the morainic ridges. The moraines though filled with gravelly pockets usually have at surface a rather clayey till. The morainic ridges in the western part of the county have a thin veneer of gray till, and the drift knolls formed by the Keewatin ice include large masses of red till with the gray till.

The rural population is only 35 persons to the square mile, and the development of intensive farming is less than is usual on the outskirts of a large city. Ordinarily farming is carried on right up to the city limits, and crops of hay are relatively large.

Percentages of Classes of Land in Ramsey County

	Square miles	Per cent
Red drift moraine, chiefly pebbly clay loam	36	22.36
Red drift outwash, gravelly loam	15	9.31
Gray drift moraine, chiefly pebbly clay loam	48	29.81
Gray drift outwash, sandy to gravelly loam	15	9.31
Dune sand	18	11.18
Swamp and bogs	14	8.70
Valley alluvium, sandy	5	3.11
Rock terraces and rocky valley beds	10	6.22
	161	100.00

Farm and Crop Data for Ramsey County from Census of 1910

Rural population 5,647 or 35 per square mile	
Per cent of land in farms	58.8
Per cent of farm land improved	68.0
Average acres per farm	56.7
Average improved acres per farm	38.6
Value of all farm property	$9,726,904
Per cent of increase 1900 to 1910	74.8
Value of all crops in 1909	$1,072,780
Cereals (oats, corn, barley, wheat, rye)	$197,577
Other grains and seeds	$2,323
Hay and forage*	$254,970
Vegetables	$383,896
Fruits and nuts	$23,825
All other crops	$210,189

* Tame grass, 16,175 tons; wild grass, 5,552 tons.

A. GRAY DRIFT MORAINE NORTH OF ST. PAUL

B. RED DRIFT MORAINE WITH COATING OF GRAY DRIFT NORTH OF ST. PAUL

1,300 feet above sea level, the immediate bluffs of the Mississippi being generally above 1,200 feet.

There is very little glacial material in the county, yet the presence of foreign pebbles and occasional bowlders on the uplands indicates that glaciation once extended over nearly all the county, there being only a few square miles in the southeast part in which drift pebbles have not been noted.

The uplands are covered by loess, except a narrow strip that extends from St. Charles eastward past Utica and thence southeast to Fremont. The part between Utica and Fremont has a light sandy soil from the breaking down of the sandstone formation which underlies it. To the west of Utica the soil is more clayey, being derived to some extent from the disintegration of limestone. In the loess-covered portion there is generally a reddish brown residuary clay between the rock and the loess. The glacial pebbles and bowlders are often imbedded in this residuary clay, which was evidently disturbed to some extent by the overriding ice.

The valleys are often bordered by precipitous rock bluffs, but even the small tributaries have wide bottom lands with a fertile soil. The Mississippi valley had been filled by sand and gravel to a level more than 100 feet above the present stream, and the tributaries were graded to a corresponding height. The glacial river which flowed from the outlet of Lake Agassiz removed much of the filling from the Mississippi valley, but in the tributaries it is still present in large amount.

At the time of settlement, the greater part of the county had a somewhat open forest which was easily cleared, and the southwest part was prairie. Farms were therefore rapidly developed on the uplands as well as in the Mississippi bottoms.

Percentages of Classes of Land in Winona County

	Square miles	Per cent
Upland without loess, soil with underlying rock	27	4.24
Loess covered uplands and slopes	500	78.45
Rough stony land in river bluffs	40	6.28
Gravel and sand deposits of the Mississippi valley	20	3.14
Low alluvial flats of the Mississippi valley	15	2.35
Alluvial and colluvial material in tributary valleys	35	5.49
	637	99.99

Farm and Crop Data for Winona County from Census of 1910

Rural population 12,070 or 19 per square mile	
Per cent of land area in farms	91.8
Per cent of farm land improved	63.5
Average acres per farm	174.8
Average improved acres per farm	111.0
Value of all farm property	$22,718,884
Per cent of increase 1900 to 1910	58.1
Value of all crops in 1909	$2,712,087

HENNEPIN COUNTY

Hennepin County, of which Minneapolis is the county seat, has a land area of 565 square miles, and a water area in lakes and streams of an additional 70 square miles. The drainage is largely eastward or northeastward into the Mississippi, there being only a few small creeks flowing to the Minnesota River, which forms part of the southern boundary of the county. Minneapolis has, in the Falls of St. Anthony on the Mississippi, a very valuable water power, which has greatly added to the profits of the farming communities of southern Minnesota by giving milling advantages near home and an excellent market for grain. The Falls of Minnehaha, and much of the picturesque gorge of the Mississippi below the falls of St. Anthony are within the limits of Hennepin County, as is also the beautiful Lake Minnetonka and numerous smaller lakes with attractive scenic features.

With the exception of less than a square mile near Prospect Park, in the east part of Minneapolis, the entire county was covered by the Keewatin ice sheet. In the east part of the county, however, a prominent red drift moraine was overridden by the Keewatin ice and nearly all veneered with the young gray drift. Many of the red gravel plains and ridges were greatly disturbed by the encroachment of the Keewatin ice, and the red drift was thus gathered up and locally incorporated with the gray. From Lake Minnetonka to the north, south, and west, the Keewatin drift is so thick that exposures of the red drift are rare. Outwash plains of gray drift gravel and sand are extensive in the district south of Minneapolis between the Mississippi and Minnesota valleys. They are also notable within the city and northward along the Mississippi valley. These level outwash areas are largely devoted to truck gardening. The rich black loam is highly fertilized and is very productive. The moraines, on the border of Lake Minnetonka, are largely in orchards and vineyards, but elsewhere are commonly given over to general farming.

The occurrence of numerous bogs and marshy depressions among the knolls and ridges causes much waste land, while the hills and ridges themselves are too steep for easy cultivation. The percentage of improved land is therefore low, except on the sandy outwash plains, and many hillside slopes are still in forest. The presence of the forests adds greatly to the beauty of suburban homes and this perhaps more than offsets the agricultural disadvantages. Such suburban occupancy will naturally spread widely over the morainic areas west of Minneapolis, and especially around Lake Minnetonka with its numerous bays and arms.

According to the census of 1910, the area planted to potatoes in 1909 amounted to 27 square miles, and about 6 square miles to other vegetables. The gross income from vegetable raising averaged $36,500.00 per square

mile, or about $57.00 per acre. Large areas near Minneapolis are well adapted to truck gardening, and will naturally be utilized thus in the near future.

Percentages of Classes of Land in Hennepin County

	Square miles	Per cent
Gray drift moraine (partly over red drift moraine) soil pebbly clay loam	195	34.49
Gray drift till plain, pebbly clay loam	111	19.65
Gray drift outwash and glacial drainage, sandy gravel	116	20.53
Dune sand	4	0.71
Valley alluvium, largely sandy	35	6.19
Rock areas	2	0.35
Marshes and bogs	102	18.06
	565	100.00

Farm and Crop Data for Hennepin County from Census of 1910

Rural population 18,806 or 37.6 per square mile*	
Per cent of land in farms	78.6
Per cent of farm land improved	66.7
Average acres per farm	73.8
Average improved acres per farm	49.2
Value of all farm property	$34,967,221
Per cent of increase 1900 to 1910	75.6
Value of all crops in 1909	$4,132,598
Cereals (corn, oats, wheat, barley, rye)	$1,341,442
Other grains and seeds	$10,398
Hay and forage†	$833,914
Vegetables	$1,237,191
Fruits and nuts	$220,574
All other crops	$489,079

* Deducting city area there remains about 500 square miles in farms.
† Tame grass, 61,186 tons; wild grass, 45,521 tons.

WRIGHT COUNTY

Wright County is situated in the south central part of Minnesota with Buffalo as the county seat. Most of the county is drained to the Mississippi by Crow River, which enters it and also forms part of its eastern boundary. Small lakes are scattered all over the county, and occupy about 23 square miles of its area of 714 square miles.

Wright County is crossed by several moraines formed by the Grantsburg lobe of the Keewatin ice field. The ice stood on the Crow valley, while the glacial drainage discharged from the moraines on the northeast side of the lobe to the Mississippi. Outwash aprons, or plains of sandy gravel are thus extensive in the northern part of the county. Smaller ones lie along Crow River valley, which subsequently carried an important line of glacial drainage into the Mississippi. The outwash plains are covered to some extent with a loam which increases their fertility.

Although this county was covered with heavy hardwood forest, it has nearly all been converted into farm land, there being 90.3 per cent of the county in farms. Of this, however, only about 60 per cent is im-

A. LOESS-COVERED DRIFTLESS AREA NEAR CALEDONIA

B. VALLEYS BORDERED BY LIMESTONE TABLELANDS NEAR HAMPTON

roved. Part of the unimproved land is in swamps, but nearly every farm has a few acres of wood-lot. The moraines, though having many small knolls, and a somewhat varied soil, ranging from clayey to gravelly, are developed agriculturally nearly as much as the relatively smooth till plains with prevailing clay loam soil.

Percentages of Classes of Land in Wright County

	Square miles	Per cent
Gray drift moraine with clayey to mixed soil	186	26.91
Gray drift till plain, chiefly pebbly clay loam	230	33.28
Outwash plains of sandy gravel and sandy loam soil	140	20.26
Swamps and bogs	135	19.52
	691	99.97

Farm and Crop Data for Wright County from Census of 1910

Rural population 20,064 or 29 per square mile	
Per cent of land area in farms	90.3
Per cent of farm land improved	59.5
Average acres per farm	104.7
Average improved acres per farm	62.3
Value of all farm property	$27,922,225
Per cent of increase 1900 to 1910	97.9
Value of all crops in 1909	$3,477,587
Cereals (wheat, corn, oats, barley, rye)	$2,586,307
Other grains and seeds	$13,147
Hay and forage*	$456,393
Vegetables	$208,349
Fruits and nuts	$38,097
All other crops	$175,294

* Tame grass, 53,698 tons; wild grass, 52,017 tons.

MEEKER COUNTY

Meeker County is located in the south central part of Minnesota, with Litchfield as the county seat. The drainage is almost entirely eastward by the two forks of Crow River to the Mississippi. A small area near Eden Valley, however, drains northward to Sauk River, and thence northeast to the Mississippi. At one time in the course of the melting of the Keewatin ice field, this northward line carried the drainage of a large part of the county, for the Crow River valley to the east of Meeker County was still covered by the ice. A lake several miles in width then occupied the low land bordering Crow River valley between Manannah and Kingston, and discharged northward across a broad marshy valley past the site of the village of Eden Valley. This lake deposited a calcareous silt and fine sand brought into it by glacial waters from the east and south. At the south edge of the lake, an extensive outwash gravel plain, on which the villages of Litchfield and Darwin stand, was built by the waters escaping northward from the ice. This lake area and the bordering outwash and till plain lie between two large moraines which

unite a few miles west in Kandiyohi County to form the great morainic system developed on the east side of the Keewatin ice field.

The northern and earlier of the two moraines just mentioned touches the northwest and also the northeast corner of Meeker County but lies mainly in Stearns County. The southern moraine crosses the southern part of the county, and bears northeastward into Wright County. There is an extensive till plain on the southern or inner border of this moraine, extending from southwestern Meeker County into neighboring counties on the south and west.

The moraines as well as till plains are very largely of clay loam. There are, however, gravelly knolls and ridges along the outer edge of each moraine next to the outwash plains. The sediments of the glacial lake above noted are of fine sand on the edge, but are a rich silt loam in the deeper part between Forest City and Kingston. The outwash plains, though underlain by gravel, have in places a loamy soil and subsoil 2 to 4 feet deep which render them the more productive. A considerable part, however, has a light sandy soil.

Meeker County stands on the border between prairie and hardwood forest. There were groves on the prairie parts and strips of prairie extended back for some miles into the forest. The forest was of oak openings on the sandy soil, but heavier with mixed hardwood on the clay soils.

Percentages of Classes of Land in Meeker County

	Square miles	Per cent
Gray drift moraine, chiefly pebbly clay loam	190	30.59
Gray drift till plain, chiefly pebbly clay loam	260	41.87
Outwash sand and gravel plains, sandy to loamy	70	11.27
Lacustrine deposits with silt loam soil	30	4.83
Lacustrine deposits with sandy soil	40	6.44
Marshes and swamps	31	5.00
	621	100.00

Farm and Crop Data for Meeker County from Census of 1910

Rural population 12,826 or 20.6 per square mile

Per cent of land area in farms	90.2
Per cent of farm land improved	75.5
Average acres per farm	152.8
Average improved acres per farm	115.3
Value of all farm property	$21,595,297
Per cent of increase 1900 to 1910	82.4
Value of all crops in 1909	$3,310,451
Cereals (wheat, oats, corn, barley, rye)	$2,731,476
Other grains and seeds	$76,401
Hay and forage*	$351,107
Vegetables	$68,656
Fruits and nuts	$19,531
All other crops	$63,280

* Tame grass, 34,223 tons; wild grass, 58,252 tons.

A. OUTWASH PLAIN EAST OF ANOKA. DUNE SAND ON RIGHT CUT BY RAILROAD

B. OUTWASH PLAIN OF GRAY DRIFT WEST OF WHITE BEAR

C. OUTWASH PLAIN WITH THICK CLAYEY COVERING NEAR GARVAIS AND VADNAIS LAKES, NORTH OF ST. PAUL

KANDIYOHI COUNTY

Kandiyohi County, of which Willmar is the county seat, has a land area of 801 square miles, and an estimated additional lake area of 53 square miles. The lakes are especially numerous in a belt running from northwest to southeast across the county. The drainage of the northeast part is eastward by Crow River to the Mississippi, and of the southwest part is southwestward to the Minnesota River.

The great morainic system formed on the east side of the Keewatin ice sheet comes into the county from the northwest and is combined into a single broad morainic belt as far as Green Lake. It there forks, and the northern or outer member leads northeastward into Stearns County, while the southern member continues southeastward into Meeker County. There is also a weak moraine leading from Green Lake to Atwater, which is separated from the large moraine south of it by a space of about 2 miles of till plain. South of this great morainic system is a till plain extending into Renville County, the only interruption being a narrow moraine less than a mile wide that runs eastward through the southwest township of the county south of Prinsburg. There are also a few sharp gravelly knolls east of Raymond. Another till plain lies between the two members of the great morainic system east of Green Lake. This is traversed by sandy strips marking lines of glacial drainage to the middle fork of Crow River. The north part of the county is occupied by a great gravel outwash plain that extends into Pope and Stearns counties.

There is gravelly and loose-textured drift along the border of the great morainic system next to the gravel plain, but within 2 or 3 miles back the moraine becomes more clayey, though there are gravelly knolls here and there over it. The till plain has a rich black clay loam soil, such as covers the great plain along the Minnesota valley. Some of the marshes and peaty bogs may be easily drained, but others seem to be down to the level of the underground water table. The marshes and bogs are quite extensive in the gravel plain, and are in some cases 20 to 40 feet below the general level of the plains. The aggregate amount of wet land is probably as great as the area of the lakes, or not less than 63 square miles.

Percentages of Classes of Land in Kandiyohi County

	Square miles	Per cent
Gray drift moraine with gravelly or stony loam	100	12.48
Gray drift moraine with pebbly clay loam	180	22.47
Gray drift till plain, chiefly pebbly clay loam soil	378	47.19
Gray drift outwash, sandy and gravelly loam	80	10.00
Marshes and bogs	63	7.86
	801	100.00

Farm and Crop Data for Kandiyohi County from Census of 1910

Rural population 12,880 or 16 per square mile	
Per cent of land area in farms	90.4
Per cent of farm land improved	79.8
Average acres per farm	207.1
Average improved acres per farm	165.2
Value of all farm property	$22,711,957
Per cent of increase 1900 to 1910	93.9
Value of all crops in 1909	$3,410,101
Cereals (wheat, oats, barley, corn, rye)	$2,755,099
Other grains and seeds	$133,508
Hay and forage*	$401,612
Vegetables, fruits, and nuts	$62,660
All other crops	$17,492

* Tame grass, 29,094 tons; wild grass, 80,684 tons.

SWIFT COUNTY

Swift County is located in southwestern Minnesota with Benson as the county seat. The drainage is all southward or southwestward through the Pomme de Terre and Chippewa rivers to the Minnesota.

Part of the strong morainic system that was formed along the east side of the Keewatin ice field crosses the northeast corner of the county and occupies about 120 square miles. The remainder of the county is largely till plain, but small till ridges occur here and there in the southern part, and narrow moraines with strips of outwash between them cross the southwest corner of the county. A larger morainic belt traverses the northwest part of the county, and east of this is an extensive sandy outwash plain.

Some marshy land occurs in depressions in the sandy plain northwest of Benson, and there are small areas of wet land on the till plain and a few bogs in the large moraine. But the aggregate area of wet land scarcely reaches 20 square miles. The greater part of the county has a rich black clay loam soil such as characterizes the great till plain along the Minnesota valley.

Percentages of Classes of Land in Swift County

	Square miles	Per cent
Gray drift moraine, chiefly pebbly clay loam	200	27.00
Gray drift till plain, chiefly pebbly clay loam	340	45.88
Outwash plains of sand and sandy loam	181	24.42
Marshes and swamps	20	2.70
	741	100.00

Farm and Crop Data for Swift County from Census of 1910

Rural population 7,533 or 10.2 per square mile	
Per cent of land area in farms	86.2
Per cent of farm land improved	88.6
Average acres per farm	265.9
Average improved acres per farm	235.6
Value of all farm property	$18,206,728
Per cent of increase 1900 to 1910	92.4

bluffs over 900 feet. There are only a few square miles of the county standing above 1,100 feet.

The greater part of the county is strongly morainic, and is in the great morainic system formed on the east side of the Keewatin ice field. A till plain on the inner border of this morainic system occupies the southwest part of the county. Red drift is intermixed with the gray drift in notable amount in the east part of the county, and is found in outcrops and valley slopes beneath the gray drift clear to the western end of the county. The greater part of the drift, both in the moraines and till plains, is a clayey calcareous till with pebbly clay loam soil. There are, however, occasional knolls of gravel, and inclusions of gravel in the till which furnish suitable material for road ballast.

The Minnesota valley has broad terraces of sandy gravel at various heights up to more than 100 feet above the stream. On a low terrace west of Savage, the soil is in places light dune or sand but from Shakopee prairie up to Belle Plaine prairie there is usually a loamy rich soil. Rock ledges are exposed, or covered very thinly with loam and gravel, over an area of several square miles in the vicinity of Shakopee and Merriam. Low bottoms, subject in part to overflow, occupy about one fourth of the area of the valley in this county.

Percentages of Classes of Land in Scott County

	Square miles	Per cent
Gray drift moraine, chiefly pebbly clay loam	180	49.18
Gray drift till plain, black clay loam	72	19.66
Glacial drainage deposits of gravel and sand, terraces on Minnesota River	60	16.39
Low alluvial tracts along the Minnesota River	20	5.47
Marshes and bogs on uplands	34	9.29
	366	99.99

Farm and Crop Data for Scott County from Census of 1910

Rural population 9,885 or 27 per square mile	
Per cent of land area in farms	88.7
Per cent of farm land improved	64.3
Average acres per farm	136.8
Average improved acres per farm	87.9
Value of all farm property	$14,610,955
Per cent of increase 1900 to 1910	67.2
Value of all crops in 1909	$1,807,505
Cereals (wheat, corn, oats, barley, rye)	$1,380,174
Other grains and seeds	$4,808
Hay and forage*	$261,776
Vegetables	$51,012
Fruits and nuts	$14,146
All other crops	$95,589

* Tame grass, 17,148 tons; wild grass, 37,303 tons.

DAKOTA COUNTY

Dakota County, of which Hastings i[illegible] ty sea[illegible] side of the Mississippi, opposite and [illegible]

miles long, lies in the northwest quarter of the county. The drainage is largely by the Des Moines River, the outlet of Heron Lake being northward into the Des Moines. The east part of the county drains to the Minnesota River, while the southwest part is drained by Little Sioux River into the Missouri River drainage.

A prominent moraine on the west side of the Des Moines runs north to south across the county and rises in places above 1,500 feet. A similar altitude above sea level is attained in the extreme southwest part of the county which is crossed by another moraine. There are two weak moraines east of the Des Moines, separated by a till plain about 6 miles wide. A more extensive till plain covers the western part of the county. The moraines are very largely of clayey till. The till plains have a rich black clay loam soil, and portions of the plains in the western part of the county have a thin deposit of silt over the till.

A narrow gravelly strip follows the Des Moines valley for a few miles below Windom, but in the southern part of the county the Des Moines valley has bluffs of till to a height of nearly 100 feet above the stream.

Percentages of Classes of Land in Jackson County

	Square miles	Per cent
Moraines chiefly of clayey till, pebbly clay loam	260	37.04
Gravelly morainic drift with stony loam soil	10	1.42
Gravel in Des Moines valley	17	2.42
Till plain, black clay loam	405	57.69
Marshes and bogs	10	1.42
	702	99.99

Farm and Crop Data for Jackson County from Census of 1910

Rural population 10,539 or 15 per square mile	
Per cent of land area in farms	91.6
Per cent of farm land improved	86.2
Average acres per farm	215.8
Average improved acres per farm	186.1
Value of all farm property	$26,357,716
Per cent of increase 1900 to 1910	86.4
Value of all crops in 1909	$2,750,726
Cereals (corn, oats, barley, wheat, rye)	$2,163,845
Other grains and seeds	$92,197
Hay and forage*	$392,087
Vegetables	$73,214
Fruits and nuts	$19,574
All other crops	$9,809

* Tame grass, 48,787 tons; wild grass, 46,386 tons.

NOBLES COUNTY

Nobles County is located on the south border of the state in southwestern Minnesota, with Worthington as the county seat. The drainage of the northeast part is to the Des Moines River, but the southern and western parts drain southwestward across Iowa into the Big Sioux River, and thence to the Missouri.

differs from the young gray drift in which limestone pebbles are preserved nearly to the surface.

There are strips of loess in this county entirely isolated from the large loess-covered areas of southeastern Minnesota. One strip about a mile in average width runs from New Trier southeast to the southeast corner of the county. Another small loess area lies northwest of Farmington.

Percentages of Classes of Land in Dakota County

	Square miles	Per cent
Old red drift, prevailingly gravelly loam	96	16.03
Old gray drift, prevailingly clayey loam	60	10.01
Loess, pebbleless silt loam	26	4.34
Wisconsin red drift, stony clay loam	110	18.36
Wisconsin red drift outwash and glacial drainage, gravelly loam with partial cover of silt loam	118	19.70
Wisconsin gray drift, silty clay loam	62	10.35
Alluvium and marshy bottoms along the Minnesota and Mississippi rivers	28	4.67
Outwash and glacial drainage of Wisconsin gray drift	32	5.34
Sandy river terraces	7	1.17
Rock areas and very thin drift	30	5.00
Swamps and bogs (outside river valleys)	30	5.00
	599	99.99

Farm and Crop Data for Dakota County from Census of 1910

Rural population 11,249 or 18.7 per square mile	
Per cent of land area in farms	86.0
Per cent of farm land improved	78.8
Average acres per farm	152.5
Average improved acres per farm	120.1
Value of all farm property	$22,986,004
Per cent of increase 1900 to 1910	94.9
Value of all crops in 1909	$3,177,701
Cereals (oats, corn, barley, wheat, rye)	$2,142,628
Other grains and seeds	$43,948
Hay and forage*	$483,710
Vegetables	$382,403
Fruits and nuts	$49,432
All other crops	$75,580

* Tame grass, 51,335 tons; wild grass, 11,047 tons.

GOODHUE COUNTY

Goodhue County borders the Mississippi River in southeastern Minnesota, with Red Wing as the county seat. Like Dakota County it was settled at an early date, the settlements being at first on the gravel terraces along the Mississippi and its tributaries, and soon after on the uplands.

The drainage is all eastward to the Mississippi, the north part being drained chiefly by Cannon River, and the south part by Zumbro River. The uplands are gently undulating to rolling, and are of the drainage erosion type, for this county lies outside the limits of the young or Wisconsin drift, and there has developed a broad dendritic drainage in

the old gray drift. Toward the eastern side of the county, however, the streams drop down into the deep preglacial drainage.

The uplands maintain a height of about 1,100 feet clear out to the Mississippi in the district below Red Wing, but are somewhat lower in the north part of the county. The southwest part of the county rises to 1,200 or 1,250 feet, but as the drift there is about 100 feet thick, the rock surface is about the same altitude as at the bluffs of the Mississippi. The bluffs are very precipitous, being formed largely of Paleozoic limestone, and rise 300 to 400 feet or more above the Mississippi and the lower courses of its tributaries. The Mississippi below Red Wing is expanded into Lake Pepin with an altitude of 664 feet at low water, and about 680 feet at high water stages.

Along the Mississippi and its main tributaries, Cannon River and Zumbro River, there are conspicuous deposits of fine gravel, laid down by glacial waters which escaped from the edge of the ice when it covered the upper parts of these valleys. Along the Mississippi the outlet of Lake Agassiz swept away a large part of this glacial gravel. The gravel was carried by the glacial waters into lowlands in and east of Red Wing that are outside the present course of the Mississippi but which open into the Mississippi at either end. The gravel filling reached about 800 feet above sea level in the vicinity of Red Wing, or 140 feet above Lake Pepin.

The northeast part of the county was forested, but the uplands of the central and southwest parts were prairie. A large part of the uplands has a capping of loess over the old gray drift. That in the forested part is of brown color, while that in the prairie is a dark, nearly black silt loam. The brown phase is classed by the Bureau of Soils as Knox silt loam, while the dark phase is called Marshall silt loam.[1]

A large part of the prairie portion of Goodhue County has no capping of loess, and the old gray drift is at the surface. It is largely a clayey till, and is classed by the Bureau of Soils as Carrington loam, silt loam, and fine sandy loam. In a few places gravelly knolls appear, the most conspicuous belt being immediately south and west of Zumbrota. These are classed as Miami silt loam, gravel hill phase. In some cases the slopes of these gravel hills have a capping of loess which throws the soil into the Knox series. About six square miles, however, were found to be gravelly at the surface. The gravel contains much limestone; in some cases this has been leached out to a depth of only a few inches, while in other cases it has been leached to a depth of several feet, leaving only the cherty parts to indicate its former presence.

[1] Soil Survey of Goodhue County. *Field operations of the Bureau of Soils 1912.*

Percentages of Classes of Land in Nobles County

	Square miles	Per cent
Old or pre-Wisconsin drift, largely gravelly to stony loam	66	9.14
Moraines of Wisconsin drift, chiefly pebbly clayey loam	120	16.62
Wisconsin till plain, largely black clay loam	500	69.25
Outwash and valley gravels, gravelly to stony loam	36	4.99
	722	100.00

Farm and Crop Data for Nobles County from Census of 1910

Rural population 9,358 or 13 per square mile	
Per cent of land area in farms	90.5
Per cent of farm land improved	92.8
Average acres per farm	229.9
Average improved acres per farm	213.4
Value of all farm property	$30,066,799
Per cent of increase 1900 to 1910	106.1
Value of all crops in 1909	$2,788,111
Cereals (oats, corn, barley, wheat, rye)	$2,149,629
Other grains and seeds	$85,392
Hay and forage*	$436,346
Vegetables	$93,096
Fruits and nuts	$18,312
All other crops	$5,336

* Tame grass, 56,284 tons; wild grass, 29,809 tons.

ROCK COUNTY

Rock County is the southwest corner county of the state, with Luverne as the county seat. The drainage is all southwestward to Big Sioux River. The highest land is a quartzite ridge that runs from near Luverne northward past Hardwick to Trosky, and which stands 1,650 to 1,750 feet above sea level. The lowest land in the southwest part of the county is about 1,400 feet, but on the divide between the streams an altitude of 1,500 feet is maintained nearly to the southern end of the county.

The Wisconsin or young gray drift covers only a few square miles in the northeast township, and there it is a thin veneer on the eroded surface of the old gray till. In places it has a slight ridge at the border, such being the case for two or three miles from the north line of the county on the west bluff of Rock River, but usually the drift is only 10 to 20 feet thick. There appears to have been a weak outwash from it down the tributaries of Rock River, as well as along Rock River itself.

The old gray drift contains a large amount of gravelly material, but till is interbedded with the gravel and forms part of the surface.

The southwest part of the county has a deposit of loess over the till several feet in depth, or enough to form the soil and subsoil. Elsewhere the cover of silt is thin and discontinuous.

The eastern part of the county east of Rock River has a heavy drift deposit, but the northwest quarter is very thinly coated with drift, and small outcrops of quartzite are numerous. The old till of this county,

like that of Nobles County, is not deeply leached, but it shows high oxidation, and has been greatly eroded in its thick portions.

Percentages of Classes of Land in Rock County

	Square miles	Per cent
Old drift with scanty silt cover, soil chiefly a sandy to gravelly loam	250	50.81
Loess over old drift, silt loam	170	34.55
Nearly bare rock in old drift area	30	6.10
Wisconsin till sheet, pebbly clay loam	18	3.66
Wisconsin glacial drainage	24	4.88
	492	100.00

Farm and Crop Data for Rock County from Census of 1910

Rural population 6,495 or 13 per square mile

Per cent of land area in farms	91.6
Per cent of farm land improved	93.9
Average acres per farm	239.3
Average improved acres per farm	224.7
Value of all farm property	$25,297,625
Per cent of increase 1900 to 1910	136.3
Value of all crops in 1909	$2,463,846
Cereals (corn, oats, barley, wheat, rye)	$2,042,251
Other grains and seeds	$11,516
Hay and forage*	$315,685
Vegetables	$81,350
Fruits and nuts	$7,417
All other crops	$4,827

* Tame grass, 38,791 tons; wild grass, 23,070 tons.

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Area of Different Soils in Rice County (from Bureau of Soils Report)

	Acres	Per cent
Carrington loam (chiefly moraine)	84,096	26.3
"Erosion phase" (rough moraine)	39,296	12.3
Meadow	40,832	12.8
Carrington silt loam (chiefly old till)	38,144	11.9
Fargo clay loam (chiefly Wisconsin till plain)	24,832	7.8
Fargo silt loam (chiefly Wisconsin till plain)	22,720	7.1
Peat	16,320	5.1
Carrington clay loam (chiefly moraine)	12,544	3.9
Carrington sandy loam (chiefly moraine)	11,840	3.7
Sioux sandy loam (glacial drainage)	10,752	3.4
Sioux silt loam (glacial drainage)	7,744	2.4
Marshall loam (loess)	4,992	1.5
Sioux gravelly loam (glacial drainage)	2,304	0.7
Boone sand (colluvial, residual)	2,240	0.7
Sioux fine sandy loam (glacial drainage)	1,344	0.4
	320,000	100.0

Farm and Crop Data for Rice County from Census of 1910

Rural population 11,813 or 24 per square mile	
Per cent of land area in farms	94.0
Per cent of farm land improved	77.0
Average acres per farm	125.2
Average improved acres per farm	96.4
Value of all farm property	$22,753,492
Per cent of increase 1900 to 1910	60.2
Value of all crops in 1909	$2,914,736
Cereals (oats, wheat, corn, barley, rye)	$2,110,966
Other grains and seeds	$32,511
Hay and forage*	$463,143
Vegetables	$97,766
Fruits and nuts	$29,494
All other crops	$180,856

* Tame grass 51,260 tons; wild grass 35,628 tons.

A large part of Rice County is occupied by the system of moraines which were formed on the east side of the Keewatin ice field and run north to south across the county. Among the morainic ridges and knolls there are small till plains, but the moraines are woven together in an intricate manner. The soil of the moraines is classed in the Carrington series by the Bureau of Soils, while the till plains are chiefly Fargo silt loam, and Fargo clay loam, but part of the till plain is in the Carrington series. There are numerous peat bogs inclosed among the morainic knolls and ridges, and the depressions, when not peaty, have usually a darker colored soil than the bordering higher and better drained land.

The young gray drift overrode the moraines of the red drift in northern Rice County but made so heavy a deposit that the red drift is completely concealed. Red drift material, however, is found involved in the gray, either in masses or mixed more thoroughly. The red drift may in some cases have been carried farther south than its original position. Such seems to have been the case in an exposure noted on the Rock

Island Railroad at the north line of Cannon City Township, [illegible] miles north of Faribault.

The glacial outwash and glacial drainage deposits are mapped by the Bureau of Soils as Sioux gravelly loam and Sioux sandy loam. The silt covered old gravel, in the northeast part of the county is mapped as Sioux silt loam.

LE SUEUR COUNTY

Le Sueur County is situated on the east side of the north flowing part of the Minnesota River in southern Minnesota, with Le Sueur Center as the county seat. The greater part of the county drains northwestward into the Minnesota, but the southeast corner is drained eastward by Cannon River to the Mississippi.

The eastern edge of the county is strongly morainic, and a prominent morainic spur extends westward past Elysian about [illegible] miles farther than the rest of the moraine. Between the moraine and the Minnesota valley is a till plain 10 to 15 miles wide with scarcely any knolls, but with numerous basins and small lakes. A line of glacial drainage starting at Elysian leads eastward through the moraine and down the Cannon valley.

The morainic area as well as the till plain is largely composed of clayey till with a pebbly clay loam soil. But in the morainic spur near Elysian there is a large amount of gravelly, loose-textured drift.

The Minnesota valley is about 250 feet deep along the border of this county, but part of it is filled with glacial drainage deposits of sandy gravel, the highest of which stand about 150 feet above the stream. These gravelly plains were occupied in part by prairie, but the remainder of the county was covered with hardwood forest. The outlet of Lake Agassiz removed a large part of the glacial gravel, and in places exposed rock ledges which appear along the valley up to a height of [illegible] feet or more above the stream.

Percentages of Classes of Land in Le Sueur County

	Square miles	Per cent
Gravel hills and stony loam in moraine	[illegible]	[illegible]
Moraine with pebbly clay loam soil	12	[illegible]
Till plain chiefly pebbly clay loam soil	[illegible]	[illegible]
Gravelly outwash and glacial drainage	[illegible]	[illegible]
Rock ledges in Minnesota valley	[illegible]	[illegible]
Alluvial bottoms with variable soil	[illegible]	[illegible]
Marshes and terrace swamps on uplands	[illegible]	[illegible]
	[illegible]	[illegible]

Farm and Crop Data for Le Sueur County from Census of [illegible]

Rural population 11,347 or 24.3 per square mile

Per cent of land area in farms	[illegible]
Per cent of farm land improved	[illegible]
Average, acres per farm	[illegible]

Farm and Crop Data for Le Sueur County (Continued)

Average improved acres per farm	73.5
Value of all farm property	$20,048,441
Per cent of increase 1900 to 1910	80.2
Value of all crops in 1909	$2,473,797
Cereals (wheat, corn, oats, barley, rye)	$2,004,730
Other grains and seeds	$3,944
Hay and forage*	$248,044
Vegetables	$69,026
Fruits and nuts	$17,761
All other crops	$130,292

* Tame grass, 31,353 tons; wild grass, 35,664 tons.

NICOLLET COUNTY

Nicollet County is situated on the north side of the great bend of the Minnesota River in southern Minnesota, with St. Peter as its county seat. The drainage is all south or east to the Minnesota, but in much of the county natural drainage lines are poorly developed, and it has been necessary to extend ditches over such areas. There are several shallow lakes on the uplands occupying about 20 square miles, around which is marshy land with an additional 10 square miles. Ditching has, however, reduced the marshes and wet areas very materially.

The county is nearly all a prairie till plain with rich black loam soil and pebbly clay loam subsoil. A morainic strip with two somewhat distinct ridges or members leads across the western part of the county from Clear Lake past Klossner to the Minnesota valley at Cortland. The moraine has some knolls of gravel, but always with clay till surface.

The Minnesota valley is cut to a depth of about 200 feet below the bordering till plain. Near St. Peter, and also near Cortland, there is a wide remnant of a glacial gravel deposit, but generally the low bottom lands extend back to the bluffs. The glacial river that was the outlet of Lake Agassiz uncovered rock ledges in the east part of the county, and between Cortland and New Ulm.

Percentages of Classes of Land in Nicollet County

	Square miles	Per cent
Moraines largely clayey, pebbly clay loam	40	9.03
Till plains chiefly black clay loam	330	74.49
Upland marshes and bogs	10	2.25
Glacial gravel in Minnesota valley	9	2.03
Alluvial deposits in Minnesota valley	50	11.28
Rock outcrops in Minnesota valley	4	0.91
	433	99.99

Farm and Crop Data for Nicollet County from Census of 1910

Rural population 7,929 or 17.9 per square mile

Per cent of land area in farms	92.5
Per cent of farm land improved	72.3
Average acres per farm	185.4
Average improved acres per farm	134.1
Value of all farm property	$15,863,289

Farm and Crop Data for Brown County from Census of 1910

Rural population 10,010 or 16.35 per square mile	
Per cent of land area in farms	93.3
Per cent of farm land improved	84.2
Average acres per farm	202.2
Average improved acres per farm	170.3
Value of all farm property	$20,999,282
Per cent of increase 1900 to 1910	57.5
Value of all crops in 1909	$2,930,658
Cereals (wheat, corn, oats, barley, rye)	$2,445,529
Other grains and seeds	$29,067
Hay and forage*	$330,596
Vegetables	$70,266
Fruits and nuts	$12,788
All other crops	$42,412

* Tame grass, 20,657 tons; wild grass, 71,440 tons.

REDWOOD COUNTY

Redwood County is situated on the south side of the Minnesota valley in southern Minnesota, with Redwood Falls as the county seat. The drainage is all eastward to the Minnesota River, chiefly through Redwood and Cottonwood rivers. The county is largely a plain standing between 1,000 and 1,200 feet, but the southwest corner rises to about 1,400 feet. The Minnesota valley is cut to a depth of 200 feet below the bordering plain, the river being 842 feet at the western, and 804 feet at the eastern limits of the county.

There are several moraines formed along the south edge and southeast end of the Keewatin ice field as it was melting back across the plain that borders the Minnesota River. One morainic belt is in the southwest corner of the county; another follows the north side of the Cottonwood, and another the north side of the Redwood valley. This last moraine splits into three narrow ridges that run southeastward through the eastern part of the county. There is also a later moraine in the extreme northwest corner of the county. The moraines are usually a clayey till, but in places gravel knolls become conspicuous. This is notably the case in the slender ridges in the east part of the county. There is a prominent strip of gravel knolls and ridges immediately east and south of Revere, which trends southwestward toward a moraine in Cottonwood County, instead of paralleling the course of moraines of this region. It is not, however, a definite gravel or esker ridge, but has much irregularity of form and of structure, for considerable till is included with the gravel.

Glacial drainage seems to have been rather weak along the border of the moraines, and deposits of sand and gravel are scanty. It is probable that the water was ponded in places along the edge of the ice during the development of some of the moraines. The plains bordering the moraines have a rich black soil, as this was a prairie region.

of the Des Moines River. There are several chains of lakes in Martin County, which have been interpreted by Upham in his report on that county to mark the line of interglacial valleys, which have been irregularly filled by the deposits of the latest or Wisconsin till. The soil separating the Wisconsin till from the older till below it is to be seen in a few places along the bluffs of the lakes.

The surface slopes gently from southwest to northeast, being about 1,400 feet in the southwest corner, and about 1,050 feet in the northeast corner of the county.

Three morainic belts traverse the county from northwest to southeast, which were formed on the southwest side of the Minnesota valley lobe of the Keewatin ice field. They are all rather diffuse knolly tracts with nearly plane areas inclosed among the knolls and ridges. The middle belt, which traverses the central part of the county, is spread over a width of 4 to 8 miles, and the others are generally 2 to 4 miles wide. Gravelly knolls are scattered along the moraine, and occur to some extent along the bordering till plain, but the moraines are generally of clayey till. The plains have a rich black clay loam soil, though a small area northwest of Ceylon has a sandy soil.

Percentages of Classes of Land in Martin County

	Square miles	Per cent
Gravelly knolls in moraines and elsewhere, stony loam	30	4.26
Clay moraines with pebbly clay loam soil	175	24.86
Till plain with black clay loam soil	470	66.76
Gravelly and sandy soil on plains and valleys	20	2.84
Wet land, marshy and boggy	9	1.28
	704	100.00

Farm and Crop Data for Martin County from Census of 1910

Rural population 11,453 or 16.3 per square mile

Per cent of land area in farms	93.0
Per cent of farm land improved	88.1
Average acres per farm	196.1
Average improved acres per farm	172.8
Value of all farm property	$30,512,250
Per cent of increase 1900 to 1910	87.8
Value of all crops in 1909	$3,155,826
Cereals (oats, corn, wheat, barley, rye)	$2,504,379
Other grains and seeds	$25,916
Hay and forage*	$458,496
Vegetables	$88,679
Fruits and nuts	$36,757
All other crops	$41,599

* Tame grass, 49,845 tons; wild grass, 49,541 tons.

JACKSON COUNTY

Jackson County, of which Jackson is the county seat, is located on the southern border of the state. The land area is 702 square miles and the lake area about 20 square miles. Heron Lake, a body of water 12